GRANITE DETERIORATION IN THE GRAVEYARD OF
SAINT JAMES THE LESS, PHILADELPHIA

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To my sister, Krista

To my sister, Krista

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CHAPTER 1: INTRODUCTION

Although the quarrying of granite for use as a building and monumental stone dates back to ancient civilizations such as Egypt, the actual use was often reserved for sculpture and choice locations in temples and monuments, including the famous obelisks and veneer in a few small rooms in the Temple of Karnak.[1] The extreme hardness of granite, as compared with other available stones like marble and limestone, precluded granite from widespread use as a building stone. With the mechanization of the quarry process, the advent of pneumatic hammers, and the development of carbide and diamond tipped saws, the hardness of granite became less of an economic consideration.

The durability of granite, related to its low porosity and non-calcareous mineral structure, made granite a popular building material, both as a building stone and for monumental and sepulchral uses. Due to the relative durability and recent widespread usage in the United States, granite deterioration has received little attention outside of academic petrological journals. There is a lack of information on the mechanisms of deterioration and options for intervention available to an architectural conservator when faced with a

deteriorated granite object or building.

After roughly one hundred years of exposure, it has become apparent that granite does in fact deteriorate, although at a slower rate than other common building stones. The superior qualities of granite as a building material led to its widespread use for tombstones, beginning in the last quarter of the nineteenth century. Marble and sandstone tombstones have been used in numerous studies as examples of stone weathering. The fact that the stones are often placed in direct contact with the soil, are relatively thin, and are exposed on all sides leads to accelerated weathering as compared with building stones which have some measure of protection provided by a roof and the surrounding stones. For these reasons, this study utilizes granite tombstones as examples of stone deterioration.

The churchyard of St. James the Less, a National Landmark located in Philadelphia, contains many granite tombstones which exhibit differing types of deterioration. The examination of these tombstones and the determination of the causes and rates of deterioration should help determine the necessity for and possible methods of intervention. This case study will

provide a review of the mechanisms of granite deterioration as they apply to gravestones, which when coupled with the analysis of the surface deterioration of the granite gravestones at Saint James the Less, may be applicable to other uses of granite as a building or monumental stone.

ENDNOTES: CHAPTER 1

(1) Mary Winearls Porter, _What Rome Was Built With_ (London: Henry Frowde, 1907), 62.

CHAPTER 2: GRANITE FORMATION, PROPERTIES, QUARRYING AND FINISHING TECHNIQUES

The weathering characteristics of granite are in part determined by the formation process, the properties of the mineral constituents, and the methods used in the quarrying and dressing processes. An understanding of these properties and processes provides a basis for understanding the complex interactions between the granite and the environment which produce various types of surface deterioration on the tombstones.

All igneous rocks are formed when magma, which is molten silica found below the earth's crust, makes its way into the earth's crust. If the magma is allowed to cool within the crust, the resultant rock is called intrusive or plutonic. These rocks are characterized by coarse grains, as the magma cools very slowly and large crystals are formed. If the magma is extruded above the earth's surface the magma undergoes rapid cooling and the resultant grains are much finer. These rocks are called extrusive or volcanic.[1] Granite is an intrusive rock that is exposed to the surface by the weathering of less durable rocks above it and by movements in the earth's surface.[2]

The coarse-grained or phaneritic texture of granite is important, as the larger the grain size, the more the minerals will behave according to their individual properties.[3] The minerals formed in the crystallization of an igneous rock depend on the elements present in the original magma and upon the changing temperature of the magma as it cools.[4] The minerals which make up granite are chiefly quartz and feldspar.

Quartz comprises up to 25% of granite and is formed from silicon and oxygen.[5] It is colorless when pure, but impurities can impart a light gray, yellow, pink or violet color. It has a glassy appearance and a hardness of 7 on the Mohs scale.[6]

Plagioclase and orthoclase feldspar can constitute over 50% of granite.[7] Both types of feldspar have a hardness of 6 and form elongated crystals in igneous rocks. Plagioclase feldspar forms from aluminum, silicon, oxygen, and either sodium or calcium, and varies in color from white to gray. Orthoclase feldspar contains potassium, aluminum, silicon, and oxygen, ranges in color from white to gray but is often a salmon pink color, and is much more common in granite than either the sodium-rich or calcium-rich plagioclase feldspars.[8]

Other minerals present can include either mica in the form of muscovite or biotite, and amphibole, usually in the form of hornblende. The micas have a hardness of between 2-3 on the Mohs scale and can easily split into parallel sheets due to a weak bond between the more strongly bonded layers.[9] Muscovite ranges from a clear to a light gray, green or brown color, and is less common than biotite, which is characterized by a black, dark green or brown color. Although different in structure, both micas contain potassium, aluminum, silicon, oxygen,and hydrogen. Biotite also contains magnesium and iron as well.[10] Amphibole is a complex family of hydrous calcium, sodium, magnesium, iron, and aluminum silicates of which hornblende is a common member. The colors range from dark green to black and the mineral has a hardness of between 5 and 6 on the Mohs scale.[11]

Due to the mineral constituents and the process in which it is formed, granite exhibits properties which make it an ideal building and monumental stone. Granite has an extremely low porosity, between 0.3 and 1.5%.[12] The bulk density (gm/cm3) is 2.5-2.8.[13] Granite is also very hard due to the hardness of the minerals, and commonly has compressive and tensile strengths higher than other common building stones.[14]

Beyond the formation process and mineral properties of granite, the quarrying and cutting processes also affect the weathering characteristics. Although bronze chisels were found in Egyptian quarries,[15] early granite quarrying techniques are not well documented.[16] At this point in time quarries use a variety of extraction methods, the choice of which is somewhat dependent upon the relation of the granite mass to the topology of the site and the structure of the granite itself.[17] The oldest methods depend upon the advantageous manipulation of the rock structure, either on the large scale in the form of fissures and planes of weakness,[18] or on the particle level using the cleavage planes between the minerals. The methods most commonly used in large scale quarrying today depend upon the force of explosives and the hardness of the materials used to tip the saws.

The oldest methods used different forms of wedges to split off sections of rock. One type of wedge method still employed is called plugs and feathers, referring to the wedge shaped plugs and the two curved or angled guides for each plug. In this method, a linear series of holes are drilled in the granite face, usually 6-9" apart, 3-6" deep and with diameters of an inch or less.[19] The metal feathers are inserted in the hole opposite each

other and the plug is placed in the center. The plugs are tapped into the granite in succession along the line, repeating the tapping process several times, allowing the granite to split along the particle cleavage planes, producing a flat rough face.

The introduction of black powder blasting issued in a new approach to granite quarrying which relied on extreme forces and very hard tipped saws to extract the stone, and which characterizes the majority of granite quarrying operations today. Low powered blasting using dynamite, black powder, ammonium nitrate fuel, and slurries of water, fuels and oxidizers are commonly used in many granite quarries, and have drastically increased the output of the quarries since their introduction.[20] Although used in a variety of situations, in dimension stone quarrying the charges can be used to open up channels to facilitate removal of large blocks and to loosen the blocks from the face.[21] Compressed air, from 70 - 100 psi, has also been used in conjunction with dynamite and black powder blasting, and can save time if the quarry and rock conditions permit its usage.[22] The plug and feather method is often used in conjunction with these other quarrying methods, although using air hammer drills.[23]

Jet flame cutting is another technique which uses a flame that moves at five times of the speed of sound and burns at 5000F. As the minerals that formed the granite have different coefficients of expansion, stresses are built up internally which cause the heated areas to spall off. This technique is used in chanelling, cutting, and dressing.[24]

Another recently developed method utilizes continuous belt wire saws which cut by abrasion with the additions of sand and water. The cut progresses about two inches and hour and can descend 50-70 feet deep.[25]

After the granite has been removed from the rock face, saws tipped with either diamond or tungsten carbide are used to reduce the large blocks into smaller square blocks or into slabs.[26]

The finishing techniques and tools used on granite, although now mechanized, remain largely unchanged with the one exception of the jet flame finish discussed earlier. The polishing and dressing processes are now automated or at least augmented with compressed air tools.

Polishing is a process of rubbing the stone surface with increasingly fine grades of abrasive until the surface is completely smooth and reflects light. Granite is a stone which takes a polish extremely well. Polishing machines are now automated, but previously there were hand operated rotating-disc polishing machines. These machines used a silicon carbide grit in a range of grades, the final polishing using a felt pad and tin oxide.[27]

Monumental stone relief finishes are not usually carved but shot-blasted. A rubber stencil is placed on the stone and the whole area is blasted with silicon carbide grit. The rubber overlay protects the stone underneath while the unprotected stone is evenly removed by abrasion.[28]

The tools used for finishing granite have not changed much through time, although the order of usage of the tools has changed.[29] Many of the hand finishing tools are also directly powered by electric or compressed air instead of separate hand held hammers and mallets. The cost of the labor intensive methods of hand finishing has favored the use of machined finishes, such as polishing, grit blasting and sawn blocks. However, traditional

carving and dressing tools are still used where special surface finishes are required.

The tools used on granite dressing include chisels, bolsters, punches, claw tools, pitchers, and bush hammers. The pitchers have wide, flat and thick ends and are used first to remove large pieces of excess stone, followed by a punch which is pointed, used for the rough shaping. Next the surface is worked over with a claw tool and finished with a variety of chisels and bolsters. The bolster has a wide and flat edge and is used for shaping and surfacing. The tips of the chisels can be either straight, skewed, pointed, or bullnosed.[30] Bushhammers have a head of individual pyramidal points and are widely used on granite to produce a fine, level surface finish appropriately named after the tool. Most finishing tools are now tipped with tungsten carbide or carbon steel.[31]

It is useful to understand the finishing and quarrying techniques of granite as they may have created conditions in the stone surface which will affect how the stone weathers once exposed to the environment. Information concerning the formation, properties, and mineral constituents of granite can also be relevant in understanding the different environmental reactions which lead to surface deterioration.

ENDNOTES: CHAPTER 2

(1) Ehard M. Winkler, Stone: Properties, Durability in Man's Environment (New York: Springer-Verlag, 1975), 1-2.

(2) Richard Muir, The Stones of Britain (London: Michael Joseph, 1986), 12.

(3) Winkler, Stone, 1.

(4) Edward J. Tarbuck and Frederick K. Lutgens, The Earth: An Introduction to Physical Geology 3rd ed. (Columbus, Ohio: Merrill Publishing Co., 1990), 55-56.

(5) Tarbuck, 40, 60.

(6) McGraw-Hill Encyclopedia of Science and Technology 6th ed., s.v. "quartz."

The Mohs scale of hardness, developed in 1882, assigns minerals a number between 1 and 10, based upon the ability of the mineral to scratch and in turn be scratched by other minerals on the scale.

1: Talc
2: Gypsum
3: Calcite
4: Fluorite
5: Apatite
6: Orthoclase
7: Quartz
8: Topaz
9: Corundum
10: Diamond

The scale is not linear but geometric, as each number marks a two-fold increase in indentation. The hardness of a mineral corresponds to the strength of the weakest bonds, thus the van der Waals bonds of talc place it at 1 and the covalent bonds of diamond place it at 10. (Tarbuck, 36; Encycopaedia Britannica 15th ed., s.v. "minerals.")

(7) Tarbuck, 60.

(8) Tarbuck, 43-44.

(9) McGraw-Hill, s.v. "mica."

(10) McGraw-Hill, s.v. "mica."

(11) Winkler, Stone, 197.

(12) Encyclopaedia Britannica 15th ed., s.v. "physical properties of rocks."

(13) Encyclopaedia Britannica 15th ed., s.v. "physical properties of rocks."

(14) For comparison purposes, selected properties of common building stones:

	Density (g/cm3)	Porosity (%)	Compressive Strength(psi)	Tensile Strength(psi)
Granite	2.5-2.8	0.3-1.5	30,000-50,000	500-1000
Sandstone	1.9-2.5	5-35	5,000-15,000	100-200
Limestone	2.5-2.7	0.1-15	2,000-20,000	400-850
Marble	2.6-2.8	0.4-2	15,000-30,000	700-1000

Table compiled from: Encyclopaedia Britannica, s.v. "physical properties of rocks"; McGraw-Hill Encyclopedia of Science and Technology 6th ed., s.v. "rock".

(15) Porter, 59.

(16) Patrizia Balenci, et al, "Investigation on the Degradation of the Stone: XI- Historical Research on the Techniques of Working," in Conservation of Stone II Part A, 2nd ed. (Bologna: Centro per la Conservazione delle Sculture all' aperto, 1981), 165-194.

This article provides the most complete source of information on historic quarrying and dressing techniques.

(17) A.T. Armstrong, comp., Handbook on Quarrying 4th ed. (Government Printer, South Australia, 1983), 121.

(18) Hugh O'Neill, Stone For Building (London: Heinemann, 1965), 70.

(19) O'Neill, 70.

(20) Encyclopaedia Britannica 15th ed., s.v. "mining and quarrying."

(21) Halbert Powers Gillette, Handbook of Rock Excavation Methods and Cost (New York: McGraw-Hill Book Co. Inc., 1916), 572.

(22) Gillette, 578-579.

(23) Gillette, 577.

(24) O'Neill, 72.

(25) McGraw-Hill 6th ed., s.v. "quarrying."

(26) O'Neill, 91.

(27) O'Neill, 94.

(28) O'Neill, 95.

(29) Peter Rockwell, Lecture at ICCROM, Rome, August, 1989.

(30) Richard Grasby, Lettercutting in Stone (Oswestry, England: Anthony Nelson Ltd., 1989), 24.

(31) O'Neill, 96.

CHAPTER 3: MECHANISMS OF DETERIORATION

The formation process, the properties of the specific mineral constituents, and the quarrying and cutting processes taken together with the environment in which the stone is placed form the mechanisms responsible for deterioration. The mechanisms which contribute to the deterioration of granite can be grouped into three separate categories; mechanical, chemical, and biological. In practice, however, deterioration often results from the interactions of these mechanisms.

The deterioration of granite due to mechanical processes range from weaknesses and stresses formed while the magma cooled, to excessive force used in quarrying and finishing methods, to salt crystallation and stresses due to thermal expansion.

As the molten rock which forms granite does not cool all in one instant, but very gradually, planes of weakness can develop where the minerals are not strongly bound together. These are not like the parallel bedding planes of sedimentary rock, but instead tend to be irregular. These areas of weak bonds can become evident after the stone is cut and dressed. The shocks created in blasting and in the percussive blows of finishing can

serve to further reduce the bonds and create minute cracks or fissures. These allow water to ingress and thus facilitate other mechanical or chemical deterioration mechanisms.[1]

Winkler describes another process which results in a visually similar appearance of thin sheets spalling off the face of the stone.[2] Since granite is an intrusive rock, the hot magma is forced into voids or cavities surrounded by previously formed rocks. Internal stresses created in this environment are no longer confined internally when the blocks are extracted from the surrounding rock structure. The phenomenon of rock bursts and sheeting in granite quarries has long been acknowledged and is a manifestation of these same stresses.[3] Again, this process is augmented by other stresses on the stone, such as thermal expansion.

The extent to which dynamite, black powder, and other types of blasting cause the degradation of granite is unknown, but most sources agree that heavy blasting does damage the stone. Minute cracks have been found in both marbles and limestones which were extracted by blasting.[4] Another source blamed the "shattering effect of the dynamite" for the exceedingly poor condition of the granite, also stating that granite extracted using

black powder proved unacceptable as well.[5] The minute cracks serve to facilitate chemical deterioration, providing the needed space for water infiltration and salt crystallation. Quarrying operations now use low powered explosives to remove granite, but research on the effects of differing blasting charges on granite weathering has not been conducted and widely circulated, so acceptable blasting levels have not yet been determined.

The effects of finishing techniques on the weathering characteristics of marble and sandstone have been researched in a series of studies.[6] These reports used a variety of methods to evaluate stones worked with a bushhammer and with chisels. The studies showed that the surfaces worked with the bushhammer were overwhelmingly degraded, and that the chisels also caused some deterioration, both of these in the form of tiny cracks in the finished surface. The applicability of these studies to granite may be somewhat limited, as the constituent minerals of granite are mostly very hard, and thus would resist the crushing and cracking more than the marbles and sandstones.

Salt crystallization, referred to as salt fretting

when found on granite, is often named as the culprit of the fairly common surface peeling of granite, without further proof except for the visual evidence of a thin spalling area on the face of the block.[7] Winkler points out that this phenomena is also found in areas not exposed to water borne salts.[8] Given the extremely low porosity of granite (from 0.5 -1.5%) it seems unlikely that salt crystallization can cause a significant amount of deterioration, unless the surface of the block was sufficiently degraded by tiny fissures, which would greatly increase the porosity of the stone along this surface.

The differing coefficients of thermal expansion of the minerals in granite is used to advantage in the jet flame method used in quarrying and finishing. Thermal expansion within normal daily temperature ranges is also used in quarrying to finish separating granite masses after light charges of powder placed in the horizontal mass have loosened a lens shaped area.[9] If the differences in the expansion of granite minerals is such that it can be utilized to separate the rock, it stands to reason that these same forces are sufficiently strong to breakup the cut granite stones.

Geology provides a basis for understanding the

chemical deterioration of granite in universally accepted theories of progenesis. Due to the slow rate with which granite weathers, it is helpful to study how granite formations are broken down in the soil forming process. Granite deterioration due to a chemical mechanism is basically a process of hydrolysis. Most silaceous stones are affected by this process to differing degrees, depending on their mineral contents. In theory, hydrolysis can occur in pure water with the water molecules separating into positively charged hydrogen ions and negatively charged hydroxyl ions.

$$H_2O \dashrightarrow H^+ + HO^-$$

The positively charged ions in the crystalline rock structure can be replaced by the hydrogen ions and the minerals disintegrate as their internal structure is interrupted.

Most water is slightly acidic due to the formation of carbonic acid in the atmosphere when carbon dioxide dissolves in water.

$$CO_2 + H_2O \dashrightarrow H_2CO_3$$

The carbonic acid separates in water into hydrogen ions and bicarbonate ions.

$$H_2CO_3 \dashrightarrow H^+ + HCO_3^-$$

Most granites contain orthoclase feldspar, also called

potassium feldspar. The potassium is the element which is attacked in the deterioration process. When water containing carbonic acid comes in contact with granite, the hydrogen ions replace the potassium ions in the feldspar. The end product of this reaction is a clay mineral kaolinite.[10]

$$\underset{\text{potassium feldspar}}{2KAlSi_3O_8} + \underset{\text{carbonic acid}}{2(H^+ + HCO_3^-)} + \underset{\text{water}}{H_2O} \text{ ---> }$$

$$\underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_4} + \underbrace{\underset{\text{potassium ion}}{2K^+} + \underset{\text{bicarbonate ion}}{2HCO_3^-} + \underset{\text{silica}}{4SiO_2}}_{\text{in solution}}$$

As the potassium feldspar decomposes into kaolinite, the bonds with the surrounding minerals is released leaving the quartz and other minerals as unattached particles, thus contributing to the granular dissolution of the rock.

This process can be seen in the feldspar as the mineral, which usually has a pearly luster, turns cloudy and then into the clay.[11] On a larger scale, this process can be seen in huge granite formations where a crevice has given water access to the rock surface and the crack has become filled with clay This same process is also evident where large clay deposits are found above granite masses.[12]

This process of deterioration is a reaction between the granite minerals and weakly acidic water. In industrial or otherwise polluted environments the rain water often contains sulphuric acid and/or nitric acid. Both of these acids are considerably stronger than carbonic acid and it follows that these acids may be responsible for the increased deterioration of granite noticed in large cities and other industrial areas. A model for this chemical reaction could be proposed which is similar to that for carbonic acid.

Bacteria, fungi, and lichens have all been associated with the biodeterioration of stone. Although these microorganisms and lower plants can deteriorate rock, their presence on a stone does not guarantee that they are the cause of the deterioration. Several studies have proven that micro-organisms can reduce feldspar and other aluminum silicates to kaolin.[13] The deterioration processes due to micro-organisms and lower plants are largely chemical reactions, very similar to the chemical deterioration processes previously outlined, save for the origin and specific types of acids produced.

The role of the lower plants in the process of

progenesis has long been accepted. Yet the extent to which, and the mechanisms with which bacteria, algae, fungi, and lichens contribute to the breakup of rock into soil forming particles has been debated with different theories vying for acceptance. Regardless of the accepted theory, the same mechanisms of biodeterioration present on rock outcrops also lead to the deterioration of masonry. Thus the process of progenesis becomes a conservation issue when the substrate is cut stone.

The effects of biodeterioration are most noticeable on finely carved elements, such as statuary, tombstones, or monuments, so these have received the most attention and treatment. Biodeterioration is also much more of a problem in warm and humid climates. The microbial population is high in moderate semihumid and humid climates and even higher in humid tropical regions.[14] Lichens in particular are sensitive to pollutants, and generally do not thrive in urban areas. The information on the subject generally reflects these parameters and either represents large scale situations in humid, unpolluted regions or specific locations where the microclimate was conducive to microbial growth, with the majority of information addressing decorative elements.

Bacteria are involved in the production of both

sulphuric and nitric acids. Sulphur-reducing bacteria such as Desulfovibrio desulfuricans turns sulfate into hydrogen sulphide. Some strains of another genus of bacteria, Thiobacillus, can oxidize the hydrogen sulphide into sulfuric acid.[15] Nitrifying bacteria and nitrogen producing bacteria can work in conjunction to produce nitric acid from nitrogen. In the first step, two types of bacteria take either atmospheric nitrogen or nitrogenous organic matter and convert it into ammonia. A third type of bacteria can oxidize the ammonia to produce nitric acid.[16] These acids produced by bacteria attack granite, specifically the potassium feldspar minerals, through the same processes as when the sulphuric and nitric acids are present in rain.

There also exist micro-organisms which can reduce and oxidize the iron contained in minerals.[17] The iron content of hornblende increases with the acidity of the rock, and granite, as one of the most acidic rocks, often contains black colored hornblende.[18] Biotite also contains iron, and feldspar may have iron present, sometimes in the form of hematite as an accessory mineral.[19] All of these minerals may potentially be attacked by iron reducing micro-organisms.

Lichens are a lower plant form characterized by a

symbiotic relationship between fungi and either algae or bacteria. As the fungal component is responsible for the deterioration of the substrate, lichens are considered here along with other types of fungal growth. Although the rock substrates are deteriorated by mechanical and chemical mechanisms, the bulk of research addresses the chemical processes.

Deterioration due to fungal and lichen growth on masonry surfaces has been widely documented but not well understood. A study of lava flows in Hawaii found that the depth of weathered material was 71 times greater beneath a lichen cover compared to the bare surface.[20] Conversely, quarried blocks of stone left for 150 years still exhibit tool marks beneath a lichen cover.[21] In response to these observations, many theories have been offered, but a definitive explanation has not yet surfaced. Part of the problem is that as lichens have not successfully been cultivated in a laboratory, all research on the subject has been site specific. Laboratory research has been carried out on the fungal partners of lichens, which coupled with the field documentation leads to a better understanding of the mechanisms of stone deterioration due to fungal growth.

It appears that the deterioration of masonry from lichens and fungi results from the contributions of several different mechanisms, both mechanical and chemical.

Although it is generally accepted that mechanical action plays a part in the process of masonry deterioration due to the growth processes of lower plants, there appears to be some confusion over the specific mechanisms. Often repeated explanations are based upon assumptions instead of controlled observations, there being only a few examples of actual research into the subject.

Two writers comment that regardless of the other chemical or mechanical processes involved, lichen growth on masonry should be discouraged as the lichen thallus retains water which could be damaging to the stone surface.[22] In considering the potential damage it is important to note that rain water is naturally slightly acidic due to dissolved CO_2 which forms a weak carbonic acid, in polluted atmospheres other acids form which are stronger. So if water is retained in the pores and cracks by the fungal hyphae, there could be a damaging effect. However, The hyphae cell walls are gelatinous, especially those of the medulla and rhizones, which contact the

stone surface. The lichens do not have any specialized method or structures to control water loss. Both laboratory testing and field observation document that a saturated thallus will dry out in a few hours of dry weather.[23] The water content of a lichen reflects the amount of water present in the immediate environment, and thus the threat of deterioration due to water retention is of minor, if any, concern, and the claims to this effect are unfounded.

Fry studied the effect of drying gelatin on glass, gelatin on shale, and lichens on shale. The gelatin and the lichens expand when moist and contract when dry. The effect of the strong adhesion between the gelatinous hyphae and the substrate can break off particles of rock when moisture is lost and the hyphae or gelatin contracts.[24] These rock particles do not appear to be chemically altered, and are eventually enveloped by the lichen thallus, and the process proceeds to the next layer of substrate.[25]

As most masonry is porous to a greater or lesser extent, the effect of the hyphae which grow inside the pores and cracks should be considered as a possible site of mechanical deterioration. Hyphae usually do not penetrate into the substrate deeper than a few

millimeters, but hyphae have been recorded at a depth of 16mm.[26]

Several studies have attributed the deterioration of stone,at least partially, to the mechanical penetration of the hyphae, but there is no evidence to support this assumption, except for the observation that hyphal cells extend longitudinally when moistened, not radially.[27] So the uptake of water may create enough pressure for the hyphae to borrow into the substrate, but no research exists to support this theory. One study of lichens which grow on silicate rocks determined that the fungal rhizoids only penetrate the mica crystals and that the fungal hyphae tend to grow in the mica cleavage planes. The author attributed this tendency to chemical deterioration as the bonds between the layers of mica are both mechanically and chemically weak bonds.[28]

Thus the only mechanical process of deterioration that can be supported is the process whereby small particles of rock are broken off due to the adhesion of the hyphae to the substrate and the contraction of the gelatinous material in the hyphae as it dries.

The mycobionts of the lichen produce organic acids

as byproducts of the metabolism process. These organic acids are readily soluble, and are naturally occurring chelating agents. So, chelation is the weathering process resulting from the production of the acids.[29] Citric acid and oxalic acid are the two acids most often identified as active in solubilizing minerals.

There are differing explanations for the presence of oxalates on stones, and this presence has been documented as early as 1853 by J. Von Liebigs in <u>Liebigs Annals of Chemistry</u>.[30] According to some authorities, oxalates occur in plants which were used as coloring agents on stone, and oxalic acid was also used as a polish for marble.[31] Although these applications may account for some of the oxalates found on stones, mono and di-hydrate calcium oxalate has been documented on deteriorated stone beneath lichen or fungal growth as well as in the thallus itself. X-ray diffraction, a scanning electron microscope, and a polarizing microscope have been used to differentiate the calcium oxalate crystals on various stone substrates; marble columns in Venice, a marble figure on a church in Florence, a sandstone monument in Kiel, Germany, and on the stones at Borobudur, Java.[32]

The oxalic acid crystallizes to form oxalates, and is usually deposited within the thallus, accumulating

with the age of the lichen, but generally forming 50% of the total weight of the dry thallus.[33] The salts are formed by the extraction of a mineral from the substrate, usually calcium, forming calcium oxalate, but magnesium, copper and manganese also form oxalates. In this process the minerals are converted to either siliceous relics or non-cystalline weathering products.[34] The deterioration is initially visible as a pitting of the mineral surface, but the process proceeds until the cohesion of the surface is lost.[35]

Citric acid is also produced from the fungal component of lichens as well as other fungi. When a lichen-forming fungus of a silicate rock was cultured and grown with silicate rock forming minerals, the citric acid solubilized a high percent of the minerals: up to 31% Si, 12% Al, 64% Fe, and 59% Mg. Feldspar and quartz were the most resistant minerals.[36] Iron and Magnesium were most susceptible to fungal attack, and minerals such as biotite and hornblende will deteriorate more quickly than the quartz and feldspar in granite.

The chemical weathering of stones due to the growth of a lichen thallus depends upon the type of rock and upon the minerals with which it is formed. The organic acids produced by the mycobiont can remove the minerals

by a chelating mechanism, leaving an unstable residue behind.

The deterioration of masonry due to lichen and fungal growth follows the same processes as the biodeterioration of rock in a soil forming process, which can be a combination of both mechanical and chemical mechanisms. The lichen thallus often envelops pieces of the substrate which are not chemically altered, but mechanically separated by the adhesion and contraction properties of the fungal hyphae, and incorporated in the thallus by growth and movement due to the wet/dry cycling. Chemically altered minerals, often in the form of mineral salts, are also found in the lichen thallus, transported there by chelation processes. Organic acids produced by the fungal symbiont in lichens and other fungi can solubilize biotite, hornblende and feldspar crystals. Bacteria and algae also can deteriorate granite, as they produce citric, oxalic, sulphuric, nitric and other organic acids which attack certain minerals found in granite.

Damage attributed to the acid production or the chelating action of biological growths can appear very similar to deterioration caused by the acids present in

rainwater, or from the wetting of pollutants which are deposited dry on the stone surface. Feldspar and mica are the two minerals affected by chemical mechanisms due to acidic water; feldspar, mica, and hornblende are all affected by biochemical deterioration processes. Regardless of the provenance of the acidity and the minerals attacked, the result is a differential erosion of the crystals, making the surface initially pitted and then rougher as more crystals are removed by the actions of the deterioration mechanisms. Mechanical weakness, in the form of cracks, tiny fissures, stresses and weak bonds can be due to the formation, quarrying or dressing techniques, salt fretting or thermal expansion. Beyond the often disfiguring results of spalling, all of these mechanisms contribute to an acceleration of both chemical and biological deterioration mechanisms by providing protection of and access for water and biological growth.

The majority of information regarding granite deterioration comes from a geological background or has been adapted from research on other building stones. There is a lack of research specifically addressing the weathering processes of granite used as a building and monumental stone. However deficient, this information provides a preliminary basis for identifying evidence and understanding field observations.

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CHAPTER 4: DATA COLLECTION

The Church of Saint James the Less is located less than half of a mile east of the Schuylkill river, three and a half miles northwest of the center of Philadelphia. The immediately surrounding area contains residential neighborhoods, several large cemeteries, scattered industrial plants, and is near portions of Fairmount Park. The churchyard itself is roughly triangular in shape, with the ends of the church facing east and west. The gravestones of the churchyard surround the church building and are situated in lines parallel to the east/west facing walls of the church, so that the front face of the upright stones face east. There are approximately 1600 gravestones in the churchyard, of which 980 are cut from granite or granitic stones. Many of the granite gravestones are from relatively recent dates, and the earlier granite stones tend to be unpolished and of simpler design as compared with the later stones. There is a wide variety of stone types and designs within the granite tombstones, ranging from medium to coarse-grained, flat tablets to upright positioned markers, from simple designs to stones with intricate carvings. The oldest granite stone dates from 1864 and the most recent from 1989.

In order to facilitate the recording of data from the examinations of the gravestones, a granite tombstone inventory sheet was developed (Figure 1). Information necessary to identify, locate, and date the stone is included along with other types of information. Factors relevant to mechanisms of deterioration are included in the inventory based upon background research and preliminary field surveys. This information includes factors which affect the weathering characteristics of granite, factors which may augment environmental influences, and visible evidence of deterioration.

Beyond factors such as grain size and mineral constituents discussed in the chapter on deterioration mechanisms, there are other factors which affect the weathering of granite gravestones. The length of time of exposure of a gravestone is important in determining rates of deterioration, and the date of death is generally considered to be accurate within two years of the date of installation of the headstone.[1] The orientation of the faces of upright stones affects the extent to which environmental factors play a role: heat from sunshine, biological growth, abrasive winds all affect the stones unevenly. The design of the monument also affects the patterns of weathering; horizontal areas

Figure 1: Granite Tombstone Inventory Sheet (Sample)

GRANITE TOMBSTONE INVENTORY

Sample #________

Name__________________________________

Date of Death______________________

Approx. Years of Exposure__________

Lot # or Approx. Location_______________________________

Design of the Monument_______________________

Orientation of Upright Stones _________________

Surface Discoloration___________________________________
____

Minerals (color and abundance):
Quartz____________________ Feldspar_____________________
Mica______________________ Hornblende___________________

Grain Size: Coarse________ Medium_________

Visible Biological Growth_______________________________
____

Stone Condition:

Horizontal Areas____
____

Vertical Areas(SWNE)____________________________________
____

Polished Areas____
____

Unpolished Areas____
____

Comments____
____
____
____

retain water for longer periods, and decorative reliefs can guide large amounts of water along the recesses. Although there are other explanations, green or black surface discolorations on granite may be due to biological growth, and should be noted. The differentiation between horizontal and vertical areas, and polished and unpolished surfaces, follows from an initial survey which documented differences in the surface conditions of these different areas on the same stones. Distinction between orientations of the vertical faces will also be noted in the documentation of the surface condition of the stone.

The choice of gravestones which would provide a representative sample for the purposes of this study took into account both age and granite type. The range of ages includes recent stones for comparison but depends more on stones in the older age categories. Gravestones were also chosen for examination to document a range of grain sizes and differences in the appearance or relative abundance of the mineral constituents.

The methodology of the gravestone examination process first involves recording the information regarding identification, date and location as well as

other factors such as design, orientation and discoloration. The remaining information is gained on the microscopic level. The stone surfaces are examined with a 20x magnifying lens, and then documented photographically with a macro 10x lens on black and white film. These observations are made to determine the presence of minerals, the size of grains, and the presence of biological growths.

The minerals are identified by visual properties of color, luster, and structure of the crystal formations. Grain size is decided on a comparative basis, for although granite is characterized by a coarse-grained structure, there exists a range of grain sizes within the coarse-grained classification. In medium-grained stones, the crystals are visible with the magnifying lens and the mean grain size is between 1 and 5 mm. In coarse-grained stones all of the mineral crystals are visible with the unaided eye; mean grain size is greater than 5 mm.[2]

Visible biological growth is determined by the existence of green, red, or black, spherical, globular, or strand-like particles, which are usually visible with an unaided eye or the strength of the 20x magnifying lens. As the differentiation of biological matter is largely aided by color differences, the photographs do not adequately document these growths.

The illustrations referred to in the text are in Appendix A. The individual inventory sheets are collected in Appendix B.

Thirty granite tombstones were closely examined. These headstones ranged from 11 to 127 years of exposure, with a myriad of designs and locations within the graveyard. The front face of all the upright stones faced east.

The surface discolorations visible with an unaided eye varied between green and black. The green areas commonly occurred near the ground, on the north side, and on the north ends of the east and west sides of the monuments. Upon examination under magnification, the green areas appeared either globular or more elongated. Differing types of black discoloration were observed, one type which did not appear to be biological consisted of a thin irregular covering which did not scrape away. Other black areas were quite thick and always found in areas inaccessible to water washing. Another type of black discoloration was actually green under magnification. The fourth type of black discoloration always had pitting of the surface associated with it. These surfaces were

usually located on diagonal areas, such as the angle from the base to the body of an upright stone, or on horizontal areas. These surfaces were almost uniformly darkened except for the pitted areas (illustrations 1-4). A distinct type of black discoloration occurred in four stones along the edges of polished surfaces (illustrations 5 & 6).

Surface deterioration is initially more visually apparent on coarse-grained than on the medium-grained granites, and also more apparent on polished areas than on unpolished sawn finishes and rough dressed stones. The horizontal surfaces of unpolished medium-grained granites had often lost most of the marks of the sawn finish on about a half of the stones that originally had this finishing. On these stones the saw marks were still visible on the vertical areas (illustrations 7 & 8). Upon examination under magnification, it is apparent that the unpolished areas are more uniformly deteriorated, whereas the polished areas may have disfiguring pitting on an otherwise unaltered surface. This type of surface deterioration can be seen in the absence of the feldspar and mica crystals which are distinguishable in the polished surfaces (illustrations 9 & 10). The finer-grained granites mask the deterioration effects better as the crystals are smaller and less apparent when reduced

or lost.

One tombstone had large areas of the surface flaking off. The coloring of the surface of this area of the stone varied slightly from that of the rest of the stone (illustration 11). The flakes had a relatively even thickness and there were no signs of clay. Under magnification, an amber colored mineral, probably feldspar, appeared unaltered. None of the mineral crystals showed any evidence of alteration, the flaking appeared to split along the mineral boundaries (illustration 12).

The surfaces of the gravestones were examined under magnification to locate and characterize any biological growth. Beyond the obvious north side, green growths were found on other vertical, diagonal and horizontal surfaces, and on polished, unpolished and rough dressed areas.

On the north sides of the unpolished areas, the green growth was recorded growing on all of the minerals. At other orientations and on horizontal surfaces, a biological growth occurred almost exclusively on the hornblende. With an unaided eye, where the hornblende

appeared in smaller crystals, many of the surfaces with these growths had a black tinge. In granites with larger crystals, the hornblende had a distinct green color due to the concentration of the biological growths. Spherical green biological growths were also located in the recessed areas on all orientations and horizontal surfaces of rough dressed gravestones.

On polished surfaces, different types of biological growth were visible. Both green and reddish-orange strand-like elongated growths were observed along the grain boundaries, and greenish-black growths also were located on the polished surfaces of these coarse-grained stones.

The green and red elongated biological growths were also visible under the polished surface; the stones where these growths occurred were coarse-grained, and were documented on recent tombstones only exposed 18 years as well as on stones almost 100 years old.In the oldest stones there were areas which protruded from the polished surface. Along the edges of these areas the quartz crystals were chipped and flaked, and the green and red growths were visible underneath (illustrations 13 &14).

A lichen, or lichenized fungi, was documented on one

stone with almost 100 years of exposure, about one inch in diameter. Quartz crystal flakes were attached along the edges of the plant, separated from the stone surface, and there was an indentation of the stone surface beneath the growth. Clay particles were found under the growth (illustrations 15 & 16).

The quartz crystals were the most unaltered, on polished areas the crystals retained the smooth surface and typical glassy luster; on unpolished areas the quartz crystals remained in place, along with hornblende, where the other minerals had deteriorated and disappeared (illustrations 9 & 10).

In all of the gravestones studied, the mica crystals were relatively small particles, in all cases smaller than the hornblende particles. One fifth of the stones apparently did not contain mica. Under magnification, mica was often visible in polished areas and on vertical faces, but absent on the horizontal and unpolished surfaces.

The hornblende particles had a matte quality similar to charcoal. On polished areas the hornblende often broke the smooth surface with small pits, appearing as a

roughening of the crystal surfaces. On unpolished areas the particles appeared the same, but were usually the only mineral remaining with the quartz on deteriorated surfaces (illustrations 1-4, 9).

The feldspar minerals appeared most often in the common salmon pink color, but one third of the stones contained amber, light yellow, or a cloudy white feldspar. Even in the most recent gravestones the potassium feldspar exhibited early signs of deterioration. Yet most of the feldspar crystals were in excellent condition, the characteristic color and pearly luster still intact, on polished, unpolished, and rough dressed stones. Often the amber, yellow, and white feldspars were found in stones which were in better condition than the pink colored feldspar containing stones. In the stones exposed over 50 years, some of the potassium feldspar crystals were either entirely missing, deteriorated into clay, or showed signs of deterioration as the crystals became cloudy and clay-like.

On the horizontal unpolished surfaces of the finer-grained granite stones, the feldspar minerals were almost entirely absent, whereas some of the feldspar crystals were still visible on the vertical faces or on polished surfaces (illustrations 9 & 10). On polished surfaces,

even those exposed over 100 years, many of the feldspar crystals were still smooth, even with the polished plane, and still retained the pearly luster, while on the same surface in close proximity, there were clay deposits and empty holes, presumably where a feldspar crystal previously existed (illustrations 17 - 21).

The summary of the data collected from examining the granite gravestones at Saint James the Less follows the format of the survey sheet. The analysis of this information addresses the general types of evidence of deterioration and determines the causes and rates of weathering.

ENDNOTES: CHAPTER 4

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CHAPTER 5: ANALYSIS

Based upon the data gathered on the surface deterioration of the granite tombstones in the churchyard of Saint James the Less, and the previous research on granite properties and deterioration mechanisms, an analysis and interpretation can be made to determine probable causes, initiating factors, and rates of the deterioration process. The majority of information gained in the tombstone survey is based upon qualitative assessments, and not quantitative measurements, but as many of the deterioration mechanisms can be identified, at least initially, by visual evidence, the observations gained through the tombstone examination surveys provide important indicators of the causes of the surface deterioration.

The data indicated several factors which affect the deterioration processes which were not addressed in any of the relevant conservation literature consulted. Following a discussion of these topics, the specific observations of evidence of deterioration is analyzed using relevant information gathered at the site and background information from geological and conservation studies. Consideration is given to other studies which determined weathering rates of granite, and the

conclusions are compared with the conclusions of the analysis of the site observations to determine the causes and rates of weathering.

One repeated observation in gathering information on the surface conditions of the granite stones is the marked difference of surface conditions between polished and unpolished areas. Although no research has been located to corroborate this observation, the process of polishing must create surface conditions very different from the unpolished areas, and appears to provide a measure of protection to the stone. The explanation for this is relatively straightforward; the polishing process creates a smooth planar surface eliminating much of the rough surface which can harbor algae, collect and hold water. Thus the polished areas provide protection against both chemical and biological deterioration processes as the smooth surface limits both the amount of biological agents which can adhere to it and lessons the length of time of contact with water which can contain carbonic, sulphuric, and nitric acids. The presence of polished surfaces affects the influence of both chemical and biological mechanisms of deterioration of granite.

Many types of biological growth were documented, but

only in a few cases can the deterioration be directly linked with the presence of the growth; the ingress of water can precede, or augment the action of the biological growths which cause the degradation of the surface. These cases are examined along with the other cases in which biological growth was recorded on the tombstones, but there was no evidence of deterioration which could directly related to the growths.

Algae prefers to grow in moist and shaded environments, and needs a suitable substrate as it does not have highly effective means of attaching to a surface, for this reason algae is often the photobiont of lichens as the fungal component provides the necessary structure. At the graveyard of Saint James the Less, the algae was found on all sides of the monuments, with the majority on the north side. The algae grew on both horizontal and vertical surfaces, but was not found on any of the polished vertical surfaces, probably due to the fact that the planar surfaces do not provide any areas which could harbor the algae.

Another field observation, while not proof of deterioration, is interesting to note. On unpolished areas minerals had disappeared, the hornblende often was covered with a green biological growth, while the quartz

crystals were relatively free from growth. A possible explanation for this occurrence is the existence of certain micro-organisms which reduce and oxidize the iron which is present in minerals, including hornblende.[1] The hornblende does not appear to be significantly deteriorated by the presence of the growth.

The polished surfaces of several coarse-grained monuments, both of recent and lengthy exposure displayed strand-like green and red growths between the crystal boundaries. Under magnification, these growths appeared gelatinous, resembling the descriptions of fungal hyphae. These growths were also found in areas underneath the polished surface. In these areas the surface protruded, had cracks between the crystals, and the mineral crystals around the edges were flaked and chipped. Giorgio Torraca described a similar occurrence in Italy where micro-organisms were found growing beneath the glazing of tiles, where the glaze was translucent enough to permit light through to the growths.[2] It was not clear if the micro-organisms were responsible for any deterioration of the glazing or were just taking advantage of a protective shelter. In the granite stones in question, the quartz is translucent enough to transmit light, and the cracks could collect water and provide shelter, but the presence

of the quartz flakes, and relatively unaltered feldspar crystals indicates that the mechanism may not be solely chemical but possibly also biochemical and biomechanical.

Out of the thirty gravestones examined, only one lichen or lichenized fungi was found. The one recorded was approximately one inch in diameter, and as lichens grow radially an estimated 0.5- 5.0mm a year,[3] this lower plant could be from 5 to 50 years old. Flakes of quartz surrounded and were attached along the outer edges of the lichen. Clay particles cover the area underneath the lichen.

The quartz flakes are significant, as the chemical deterioration processes are not described as having any effect on quartz crystals. There are certain bacteria, fungi and other micro-organisms which can dissolve silicates, but most studies on the subject show that other minerals are solubilized in much larger percentages.[4] One study suggested that the fungal component of lichens can break off flakes of stone by the mechanical action of the gelatinous hyphae which adhere to the stone surface, and when they dry and shrink, can separate flakes of shale. Granite does not have the parallel layers and fine-grained structure of shale, but the same mechanism could be responsible for the quartz

flakes here, and as the stone in question has been exposed for 95 years, it is possible that the surface was partially degraded in that area before the lichen started growing, thus weakening the minerals. So in this case it seems probable that the damage surrounding the lichen could be partly attributed to the mechanical action of the plant, and partly to a biochemical process which produces the clay.

Some of the tombstones had other types of indeterminate biological growth, which appears to cause some minerals to deteriorate. Underneath this growth, on a polished surface, certain minerals were pitted and stained brown. Several sources also document pitting on granite surfaces due to biological growth, or in areas of very little atmospheric pollution.[5] Due to the production of organic acids and the conversion and reduction of minerals by micro-organisms, coupled with documentation of this condition in other studies, the deterioration in this case seems to be caused by the presence of the biological growth on the stone surface.

The background research on the chemical deterioration mechanisms indicated that the potassium feldspar crystals would degrade into kaolinite, a clay,

due to the carbonic, sulphuric or nitric acids in the rainwater. The information gained in the tombstone examinations confirmed this prediction, but the survey gathered other information which was not adequately addressed in previous studies.

In several recent stones which were exposed only 11 and 28 years, the orthoclase feldspars had brick-red spots in the centers of the crystals, which appeared like stains around a central spot. This condition was found on only two stones in the graveyard. One possible explanation for this observation os that the feldspar can have small amounts of an iron containing mineral, hematite, contained in the crystal which turn pink, orange, or brick-red when altered chemically.[6] So these spots are the first visible sign of either chemical or biochemical deterioration of the feldspar crystals in these gravestones.

The most visible evidence of chemical deterioration can be seen on the polished areas where the feldspar minerals are often entirely missing so that the surface has deep pitting, or the feldspar has deteriorated into clay, which is held in place by the surrounding minerals. Even on polished granite tombstones around 100 years old, only about 5 or 10% of the feldspar crystals are altered.

On unpolished stones over 50 years old the feldspar can be seen on the vertical faces, but not on the horizontal areas. Although no research has been located to corroborate this explanation, the difference in condition between the vertical and horizontal surfaces may be due to the amount of contact between the stone surface and water, the horizontal, unpolished areas tending to harbor the water, thus exposing the stone to longer contact with acids present in the water.

Another observation related to contact with water is the areas of a black surface discoloration and pitting usually located in areas that receive large amounts of runoff, such as the recessed areas in elaborate designs and the area connecting the base to the headstone. Upon examination under magnification, the white, pitted areas are bright, clean quartz crystals, and the darkened areas appear to be a thin film which is not biological and which covers all of the minerals. This is a situation of differential removal of the minerals, but no evidence of clay, or biological growth appeared, so the cause is difficult to assign to a particular mechanism, other than chemical deterioration.

There were some observations made in the survey of

the tombstones which are neither evidence of deterioration, nor factors in the process, but which deserve an explanation and comment. A type of black surface discoloration is common on the upright and elaborate horizontal gravestones. These areas are characterized by an even opaque coating and are located in areas which are inaccessible to water. A similar condition has been explained on a carbonaceous stone as a deposit of dust which is not chemically of physically bonded to the stone and has not altered the stone substrate, and is typically located in areas where rainwater cannot wash the surface.[7] Condensation is still a consideration here, for airborne pollutants can be deposited dry on stone surfaces, and then wetted by condensation which can react with the pollutant to produce acids. There also is the possibility that the pollutants can chemically bond with the stone surface, making removal difficult. However, there was no visible deterioration associated with this condition on the stones examined.

There are a few overall observations which can be made from this study about the processes and rates of the various deterioration mechanisms which affect granite. It appears that micro-organisms grow on the tombstones soon after their placement in the churchyard, and evidence of

deterioration due to biological growth has been found on stones exposed only 20 years. The process of chemical deterioration takes longer before it becomes visually apparent, but some stones exposed 11 and 18 years show initial signs of weathering. It is difficult to establish a rate of deterioration for mechanical mechanisms as either the damage is already in place before the stone is exposed to the environment, or the mechanisms work in conjunction with chemical and biological mechanisms.

There have only been a few studies which aimed at estimating a rate of deterioration of granite. Although this study did not generate quantitative measurements of deterioration, consideration of these other studies yields some information important and relevant to this study.

In 1880, Professor Archibald Geikie presented a paper entitled "Rock-Weathering, as illustrated in Edinburgh Churchyards" to the Royal Society of Edinburgh in which he refers to experiments made by a Professor Pfaff of Erlangen which estimated the annual rate of loss of material to be 0.0076mm on unpolished and 0.0085mm from polished granite.[8] Geikie remarks that the experimental stone pieces were left to weather only three

years which was not long enough to allow true rates of disintegration to be measured.[9] Geikie further wrote:

> Granite has been employed for too short a time as a monumental stone in our cemeteries to afford any ready means of measuring even approximately its rate of weathering. Traces of decay in some of its feldspar crystals may be detected, yet in no case that I have seen is the decay of a polished granite surface sensibly apparent after exposure for fifteen or twenty years.[10]

This observation supports the observation of this study that the chemical alteration of the feldspars into clay takes to roughly 20 years before becoming visually apparent.

Another study of tombstones weathering rated stones over 100 years old on a scale of 1 to 6 depending on the readability of the letters, 1 being unweathered and 6, extremely weathered. Corrected to an average 100 years, granite had an average degree of 1.33.[11] As this weathering rate is a qualitative judgment, and not a measurement, it cannot be compared with Geikies rates. However, Rahn's general remarks are useful reference;

> What little weathering occurred appeared to be the pitting developed in biotite and pyroxene minerals, particularly on the rough textured (unpolished) granite. The polished granite had virtually no evidence of weathering; saw marks were still visible on tombstones over 100 years old."[12]

It should be noted that the cemetery used in this study is located in a rural setting with very little pollution in the surrounding area, so the granite weathered better than in the urban setting of Philadelphia. The saw marks on unpolished granite tombstones at Saint James the Less were often only visible on the vertical faces; the horizontal surfaces were deteriorated enough to obscure or remove the sawn finish. The feldspar minerals with similar years of exposure were weathered in the Philadelphia cemetery and unweathered in the environment of rural Connecticut. Geikie's conclusions reinforce this observation as the feldspar minerals were deteriorated in the polluted environment of late nineteenth century Edinburgh.[13] These observations indicate that a polluted environment, which contributes to an acidic rainfall, is a major factor in the deterioration of granite. The ease with which micro-organisms and lower plants can establish growth on the granite surface also is a factor in the weathering of the stones. The determination and understanding of the mechanisms responsible for the deterioration of granite provides the framework for the consideration of appropriate methods of intervention which aim to prevent further damage and perhaps to repair the deterioration.

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(5) Ian Wainwright, "Lichen Removal From an Engraved Memorial to Walt Whitman," APT Bulletin 28, no.4 (1986): 46-51; Perry H. Rahn, "The Weathering of Tombstones and its Relationship to the Topography of New England," Journal of Geological Education 19 (1971):112-118.

(6) McGraw-Hill Encyclopedia of Science and Technology 6th ed., s.v. "feldspar."

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(8) Archibald Geikie, "Rock-Weathering as Illustrated in Edinburgh Churchyards," Proceedings of the Royal Society of Edinburgh, (1880):531.

(9) Geikie, 518.

(10) Geikie, 531.

(11) Rahn, 112-113.
For comparison, the degree of weathering of sandstone was 2.92; marble, 2.82; and schist, 2.47.

(12) Rahn, 114.
Rahn may have confused pyroxene with hornblende as the visual characteristics are similar. In the rock forming process, under certain environmental conditions, formerly crystallized hornblende becomes unstable and breaks down, forming pyroxene (McGraw-Hill, s.v. "hornblende"). Granite and granodiorite usually contain amphibole, of which hornblende is a member, and pyroxene

is found in more basic rocks such as diorite, gabbro, and peridotite (Richard Thorpe and Geoff Brown, _The Field Description of Igneous Rocks_, [Milton Keynes, England: Open University Press, 1985], 43.

(13) Giekie, 519, 531.

CHAPTER 6: OPTIONS FOR INTERVENTION

After the deterioration of an object has been documented and the mechanisms identified, it is appropriate to consider if suitable interventions exist which will halt or retard the deterioration processes. The first option is to choose not to intervene, to do nothing. This can be an appropriate choice when available treatments fail to meet standards of reversibility or retreatment, or are otherwise inappropriate. The second option is to accelerate the rate of deterioration, as is the case in controlled demolition when considerations of public safety preclude preservation concerns. However, this is a rare occurrence. The third option is to intervene in the process of deterioration.

A model has been proposed which separates the differing factors of deterioration and suggests approaches for intervention which address these individual components (Figure 2).[1] In this model a deterioration mechanism results from the interactions between the material and the environmental factors. The options for intervention can be grouped into three approaches based upon the specific component of the deterioration model they address.

```
Deterioration:

               Material   +  Environment   --->  Mechanism

                   ^              ^                   ^
Intervention:      ^              ^                   ^
                   ^              ^                   ^
        Reconstitution    Mitigation      Circumvention
```

Figure 2: Intervention Model

Reconstitution involves an alteration to the material; replacement, repointing, and reconstruction fall into this category. As the environment remains unchanged, the deterioration process will continue as before, affecting the new material. Mitigation addresses the environment without intervening in the material, and works to slow the rate of deterioration. Circumvention seeks to alter the set of necessary and sufficient conditions which give rise to the deterioration mechanism. This approach receives the most attention in the form of technological research and experimentation. This approach often introduces another material in the treatment process and effectively substitutes the deterioration mechanism of the original material for a different mechanism of the new material. If the mechanisms affecting the new material are understood, expected, and preferable to those of the original material, and if the treatment meets standards of

reversibility or retreatment, then the treatment may be an appropriate intervention.

If the deterioration is due to biological action, the model is as follows: the material here is granite, the environment is the presence of biological organisms plus water, and the mechanism produced is biochemical dissolution. There are at least three approaches for intervention.

The reconstitution approach suggests recutting the stone, which is a common practice in some cemeteries on marble gravestones where the name of the deceased or the design of the monument is deemed to be more important than the original remaining stone surface. This approach results in the loss of original design as any new work erases all traces of the old stoneworking techniques, and irreversibly alters the monument. An underlying belief to this approach is the idea that objects should look new and clean, and that it is undesirable to show the weathering of time. International charters which address the preservation of cultural property stress the preservation of original material, and the preservation of a materials patina, or the visible signs of age which develop over time. Based upon these charters, and prevailing preservation theory, the recutting of

weathered monuments is an undesirable option that serves to damage the significance of the monument.

Approaches which aim to mitigate the environmental influences are limited to repeated treatments with a biocide appropriate to the organism. There are a variety of algicides, fungicides, and general biocides available, but continued treatments are necessary as growth will reoccur as soon as conditions permit.

The final approach of circumvention aims to block the organisms, and the water they need, from access to the stone material. Waterproof and water-repellent coatings, and these coatings with biocide additives, serve to form this barrier. Waterproof coatings have fallen from grace as they serve to block all water and can create more damage than they prevent as water may enter from another route and cannot escape. Water-repellent coatings allow the passage of water vapor, but repel liquid water. The inclusion of a biocide serves to strengthen the power of the treatment against biological agents of deterioration.

Another option that circumvents the biological mechanism is the removal of the gravestone from the

environment and possibly includes the replacement with a replica. This approach is also practiced but the practice is not generally recommended as the gravestone loses some of its integrity when removed from the context of a cemetery.[2]

If the deterioration of granite gravestones is due to the action of acidic rain water, the options for intervention are similar to those outlined above. Again the gravestone can be recut but this is not an appropriate alternative. An option in mitigating the effects of the environment is to lower the amount of pollution in the atmosphere, a long term solution perhaps, but also an effective approach on a global scale as it does not alter the monument. The importance of this approach has been voiced by many international conservation organizations and individual conservators.

The circumvention options again offer a coating, preferably a water-repellent coating which is impervious to the action of the acids present in the rain water.

Some marble gravestones have been removed to interior environments to stop the deterioration process, but again, this option is a drastic measure which alters the context and significance of the monument.

The intervention proposals are based upon a model of deterioration mechanisms and aim to interrupt the process of deterioration. Choices for intervention should consider the amount of surface deterioration and the significance of the monument as well as the reversibility or retreatability of the proposed treatment.

ENDNOTES: CHAPTER 6

(1) The model used here to identify intervention options was developed by Samuel Y. Harris, and discussion of the model draws upon class lectures on the subject.

(2) For a discussion of this subject see;
Robert P. Emlen, "Protective Custody: The Museum's Responsibility for Gravestones," in Markers 1 (1979/80): 143-147.

CHAPTER 7: CONCLUSION

Information on the mechanisms of granite deterioration and appropriate interventions is not readily available to architectural conservators. This information has been gathered from sources on geology and from conservation literature pertaining to granite as well as other building stones. An understanding of the formation processes of granite, the properties of the mineral constituents, and the working techniques provides a basis for understanding the various mechanisms of deterioration and the complex interactions which produce the surface deterioration.

It should be stressed that there are many factors which affect the weathering characteristics of granite which have not been adequately researched. There are also only a few published cases of treatments to granite, such as Cleopatra's Needle in New York City. Even well known cases such as this obelisk have caused disagreement among experts as to the cause of the surface deterioration. Hopefully, more research will be conducted in the future to provide a better understanding of the mechanisms responsible for the surface deterioration of granite.

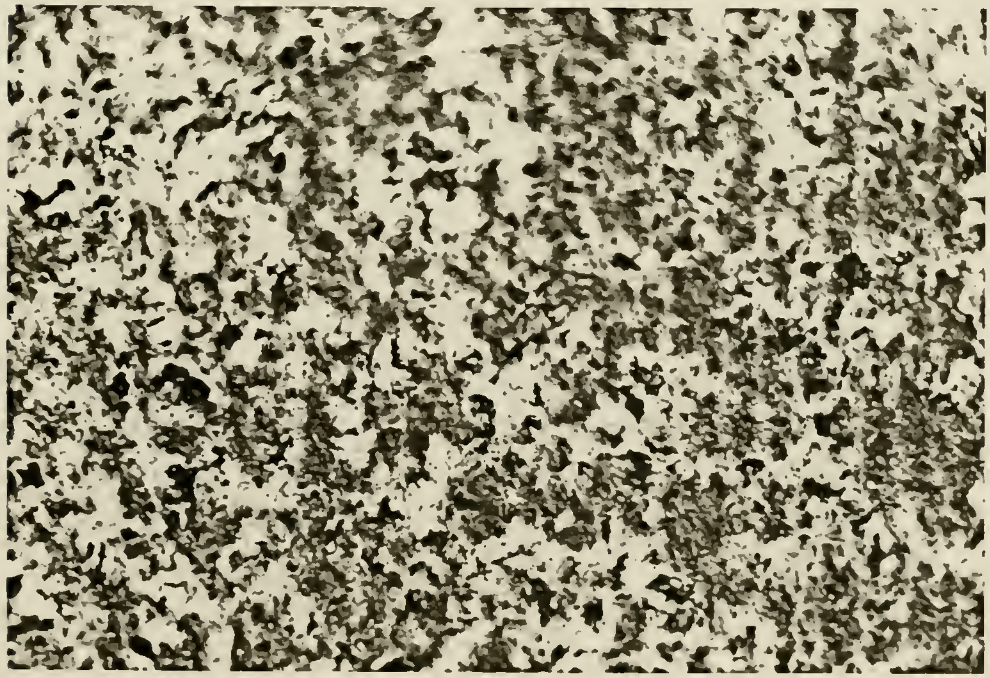
The approach for examining the granite tombstones

developed in this study assumes a familiarity with the mechanical, chemical, and biological mechanisms of deterioration and the visual evidence of these processes. The examination process is based upon a visual inspection and requires only a high powered magnifying lens. This approach is simple, and readily available as a tool for field diagnoses. Knowledge of the materials, deterioration mechanisms, and treatment options of granite will enable architectural conservators to make appropriate decisions regarding the treatments of granite monuments and buildings in an effort to preserve part of a cultural heritage.

APPENDIX A: ILLUSTRATIONS

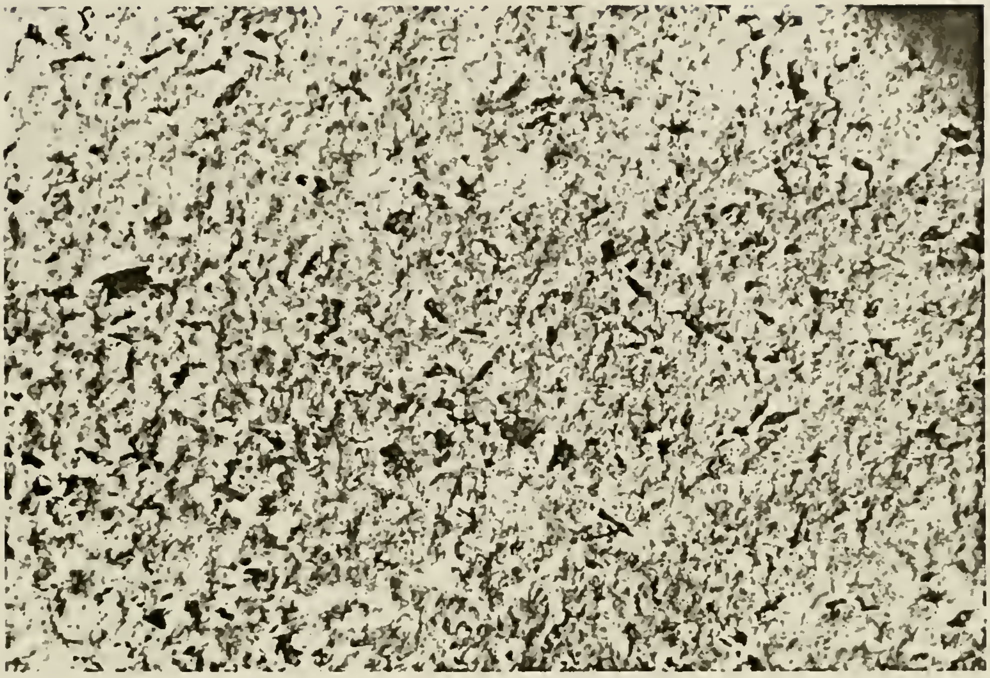
ILLUSTRATIONS 1 & 2

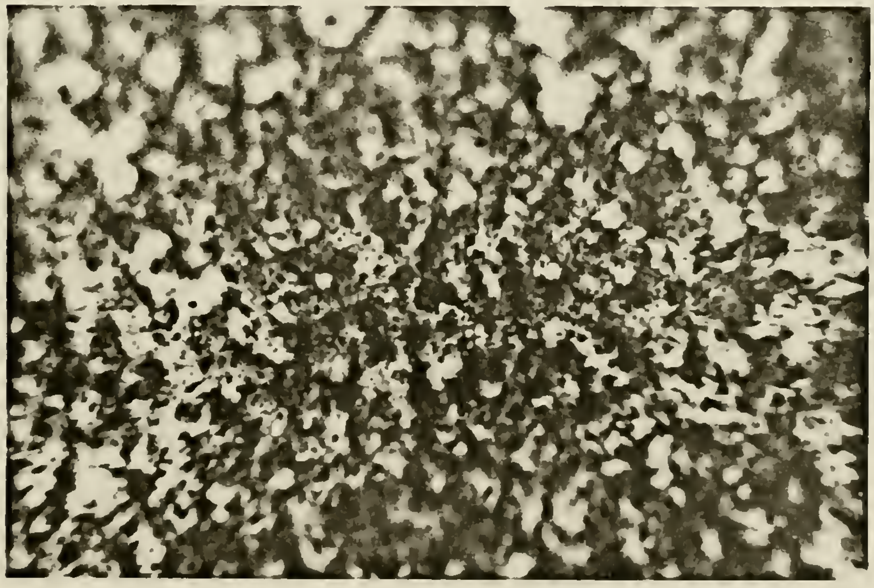
DISCOLORED AND PITTED SURFACES



ILLUSTRATIONS 3 & 4

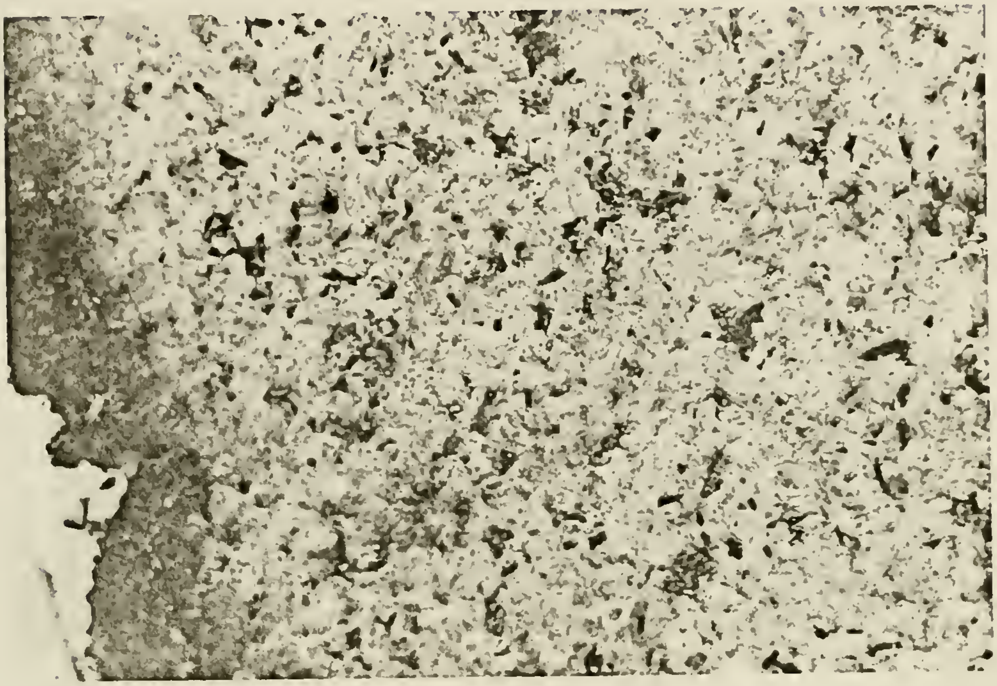
DISCOLORED AND PITTED SURFACES





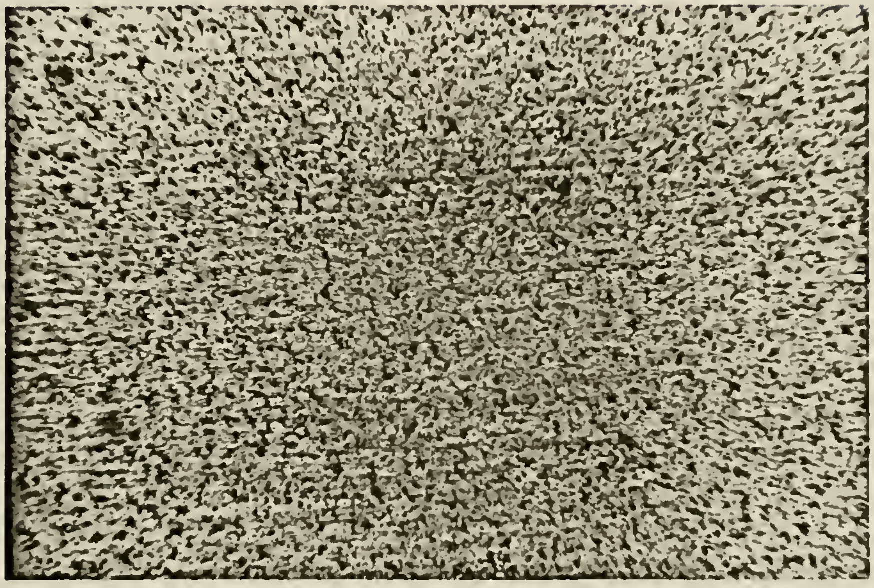
ILLUSTRATIONS 5 & 6

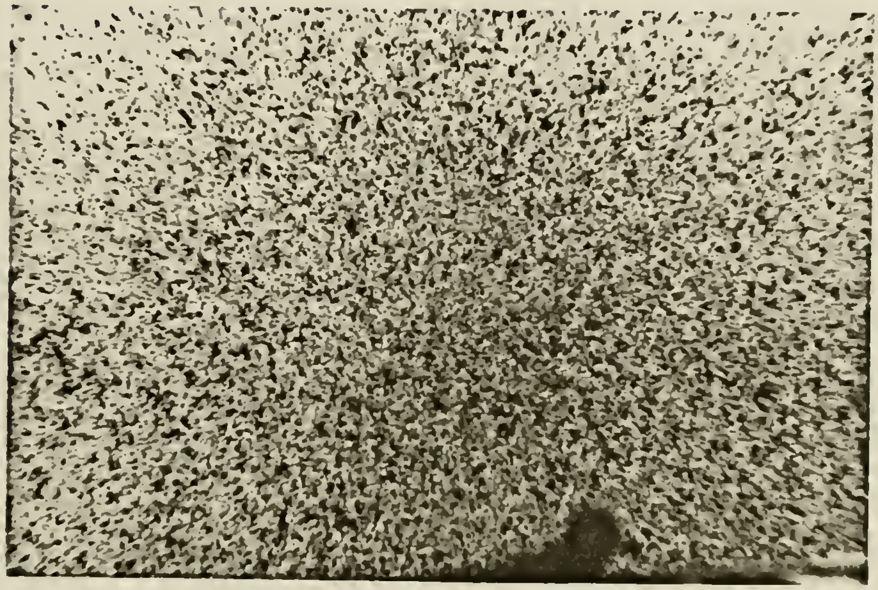
DISCOLORED AREAS ALONG EDGES OF POLISHED SURFACES



ILLUSTRATIONS 7 & 8

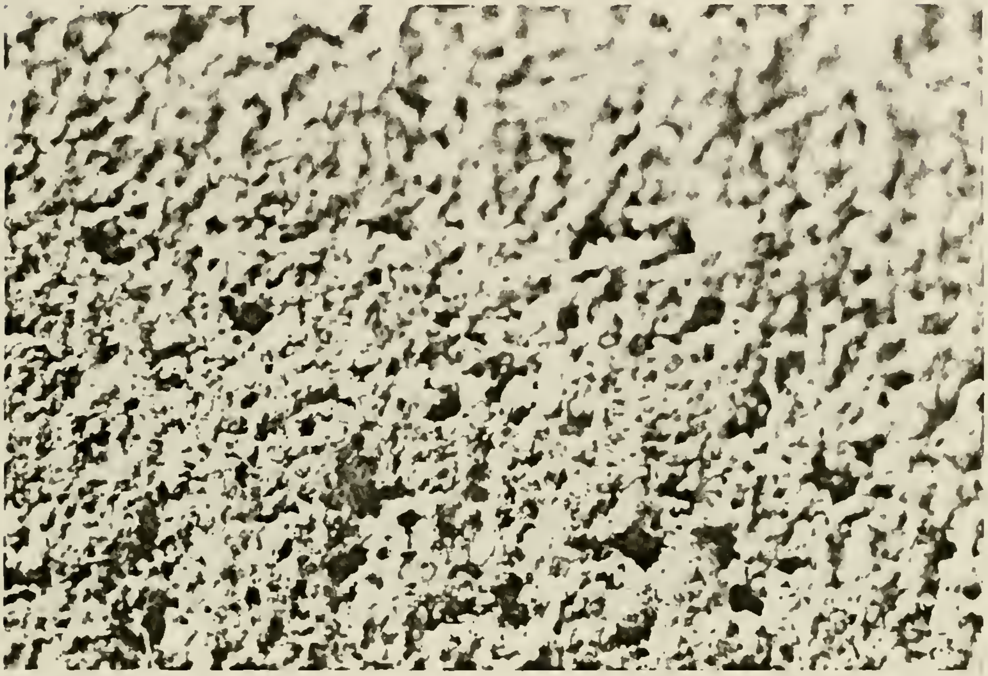
SAWN FINISH APPARENT ON VERTICAL SURFACE;
OBSCURED ON HORIZONTAL SURFACE

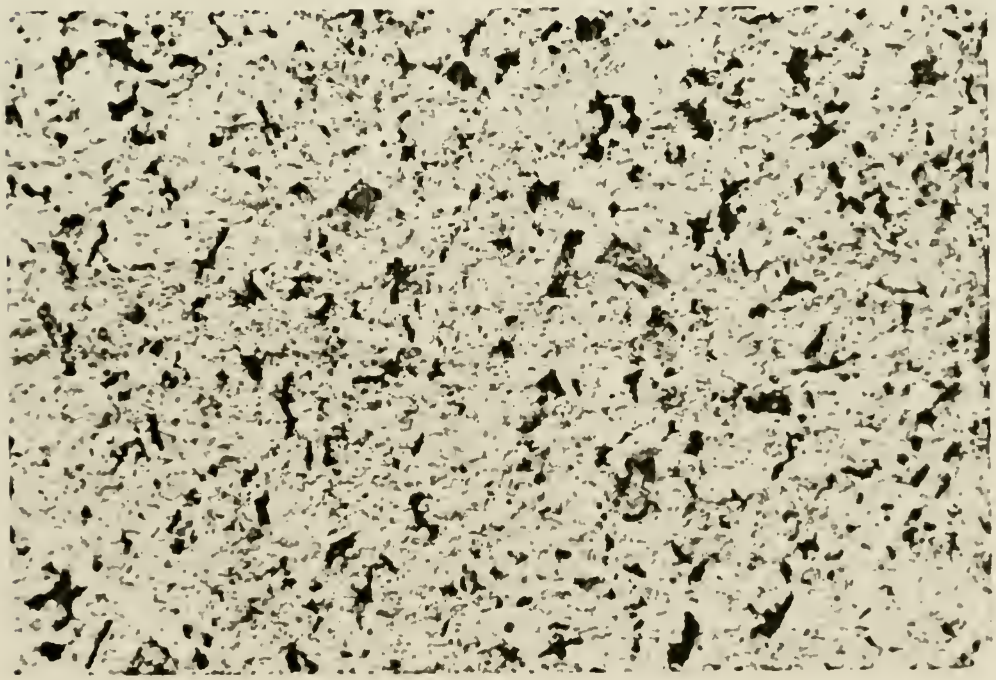




ILLUSTRATIONS 9 & 10

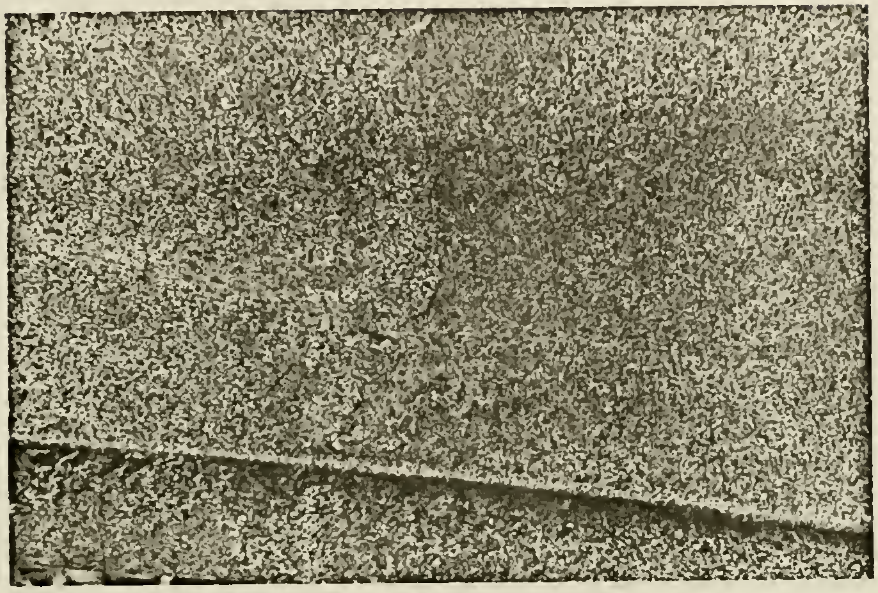
UNPOLISHED SURFACE- ONLY QUARTZ AND HORNBLENDE PRESENT
POLISHED SURFACE- ALL MINERALS PRESENT





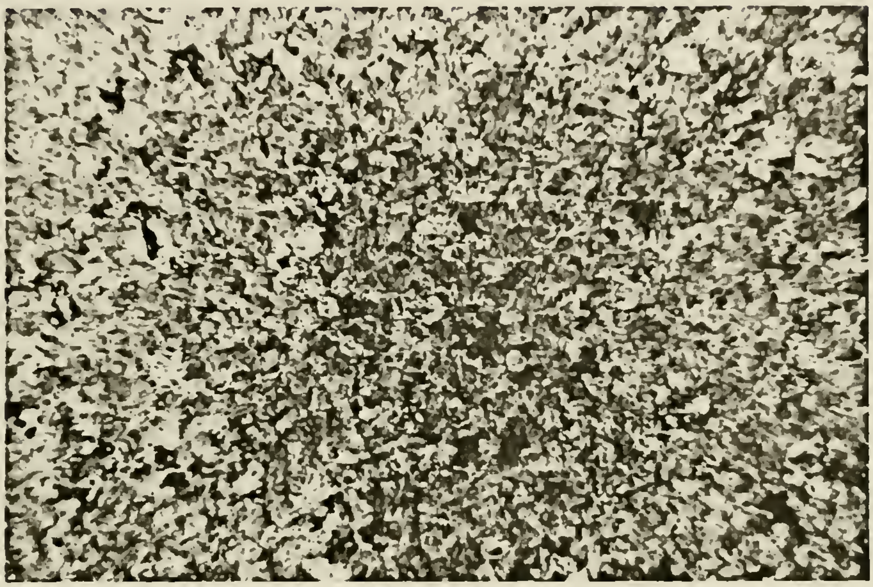
ILLUSTRATIONS 11 & 12

FLAKING SURFACE- MACRO AND MICROSCOPIC VIEW



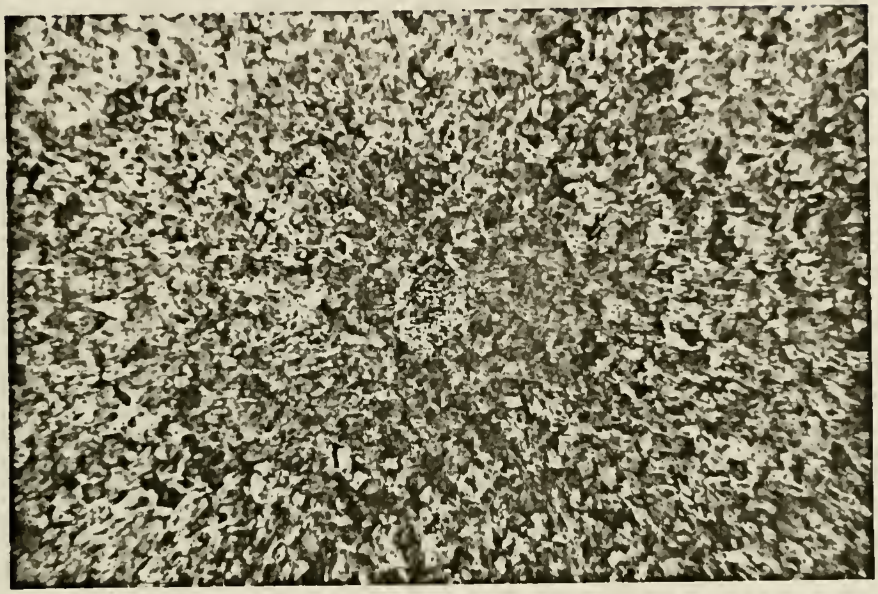
ILLUSTRATIONS 13 & 14

BIOLOGICAL GROWTHS UNDER PROTRUDED AND CHIPPED AREA



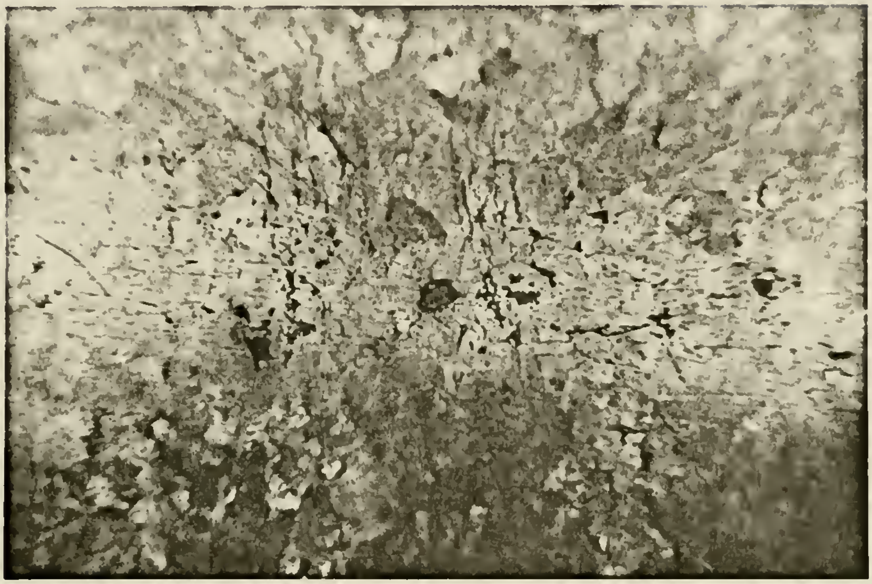
ILLUSTRATIONS 15 & 16

DETERIORATED SURFACE UNDERNEATH LICHEN



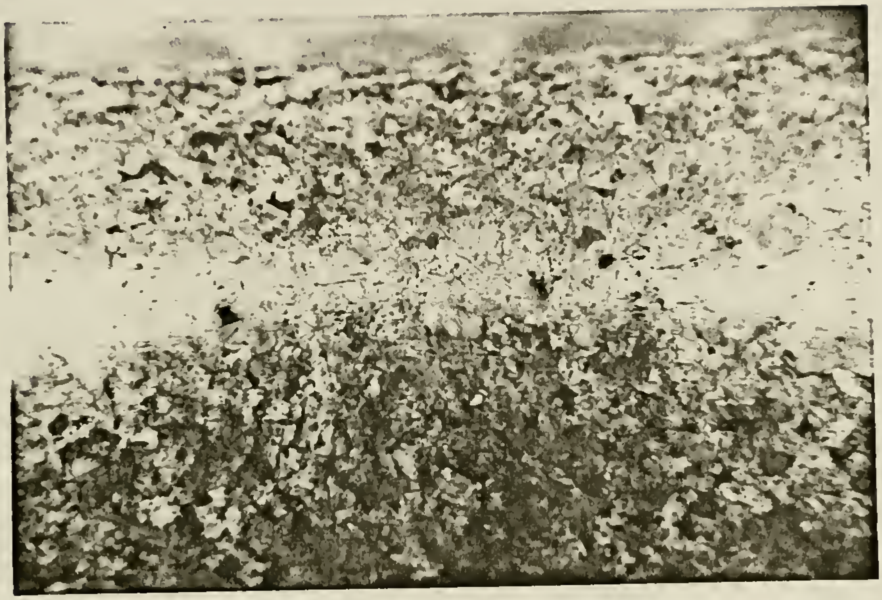
ILLUSTRATIONS 17 & 18

SURFACE PITTING WITH CLAY PRESENT



ILLUSTRATIONS 19 & 20

SURFACE PITTING WITH CLAY PRESENT



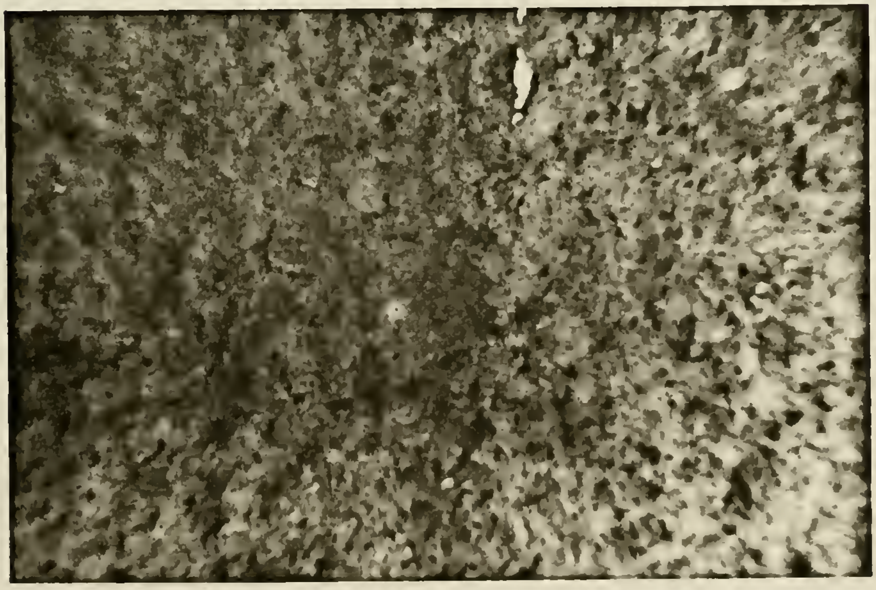
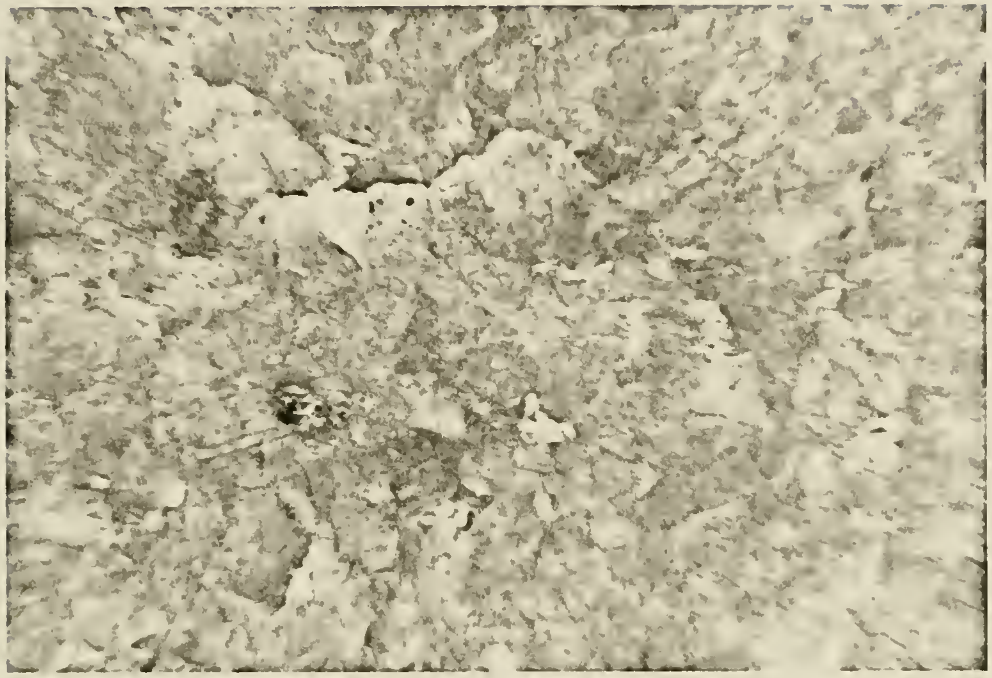


ILLUSTRATION 21

SURFACE PITTING WITH CLAY PRESENT



APPENDIX B: GRANITE TOMBSTONE INVENTORY SHEETS

GRANITE TOMBSTONE INVENTORY

Sample # 1

Name Susan wife of George Hirneison Sr.

Date of Death March 18, 1864

Approx. Years of Exposure 126

Lot # or Approx. Location 273

Design of the Monument vert cross on vault base

Orientation of Upright Stones E

Surface Discoloration dark on unwashed areas, no green

Minerals (appearance and color):
Quartz XX
Feldspar XX salmon
Mica XX silver
Hornblende XX black

Grain Size: Coarse ____ Medium XX

Visible Biological Growth No

Stone Condition:
Horizontal Areas ____

Vertical Areas(SWNE) E & W polished on cross, names on E arch polished

Polished Areas Feld. visable, on W some Feld turned to clay, mica deter. too

Unpolished Areas Feld. not visable

Comments S vert. only Q & H vis. no green biol.

GRANITE TOMBSTONE INVENTORY

Sample # 2

Name Margaret E. Phillips

Date of Death Sept. 15 1926

Approx. Years of Exposure 64

Lot # or Approx. Location Near 845

Design of the Monument upright slab with arched top

Orientation of Upright Stones E

Surface Discoloration None

Minerals (appearance and color):

Quartz XX

Feldspar XX salmon

Mica some

Hornblende XX

Grain Size: Coarse XX Medium

Visible Biological Growth Mainly on north side on unpolished area green grows mostly on hornblende & base

Stone Condition:

Horizontal Areas Top has pits with yellow colored clay

Vertical Areas(SWNE) W side has pits with yellow or light gold colored clay

Polished Areas W also some areas with red between cracks between minerals but not near Feld.

Unpolished Areas

Comments

GRANITE TOMBSTONE INVENTORY

Sample # 3

Name Moro Phillips Szarlosky

Date of Death 9 Aug 1885

Approx. Years of Exposure 105

Lot # or Approx. Location NE of church

Design of the Monument horizontal with raised cross

Orientation of Upright Stones

Surface Discoloration Black-does not scrape off granular like discoloration

Minerals (appearance and color):

Quartz XX Feldspar XX amber

Mica some Hornblende XX

Grain Size: Coarse XX Medium

Visible Biological Growth None

Stone Condition:

Horizontal Areas

Vertical Areas(SWNE)

Polished Areas flaking

Unpolished Areas general pitting not only Feld. in diagonal areas especially recessed areas near cross

Comments large areas have a thin crust exfoliating on the flat diagonal planes facing N & S also pitting on diagonal areas Areas with exfol. show remains of ivy and also do not have any clay residue

GRANITE TOMBSTONE INVENTORY

Sample # 4

Name Chandler Hare, Priest

Date of Death 1893

Approx. Years of Exposure 97

Lot # or Approx. Location 569 & 570

Design of the Monument upright cross

Orientation of Upright Stones E

Surface Discoloration black or dark green areas on horizontal and onto vert. below

Minerals (appearance and color):

Quartz XX

Feldspar XX pink

Mica XX silver

Hornblende XX

Grain Size: Coarse ____ Medium XX

Visible Biological Growth spherical and green

Stone Condition:

Horizontal Areas pitting

Vertical Areas(SWNE) ____

Polished Areas none

Unpolished Areas ____

Comments ____

GRANITE TOMBSTONE INVENTORY

Sample # 5

Name Francis Barrington

Date of Death 1894

Approx. Years of Exposure 96

Lot # or Approx. Location 490

Design of the Monument greek cross

Orientation of Upright Stones E

Surface Discoloration black and green in protected areas and on N side

Minerals (appearance and color):

Quartz XX

Feldspar XX light amber

Mica XX silver

Hornblende XX

Grain Size: Coarse ____ Medium XX

Visible Biological Growth green mostly on black minerals

Stone Condition:

Horizontal Areas very rough only quartz and hornblende visible

Vertical Areas(SWNE) ____

Polished Areas none

Unpolished Areas ____

Comments ____

GRANITE TOMBSTONE INVENTORY

Sample # 6

Name Daniel G. McComb/ Catherine B. McComb Hodgson

Date of Death 1895

Approx. Years of Exposure 95

Lot # or Approx. Location 183

Design of the Monument cube on base with brackets

Orientation of Upright Stones E

Surface Discoloration black on unpol. areas protected from rain

Minerals (appearance and color):
Quartz XX
Feldspar XX yellow/amber
Mica XX silver
Hornblende XX

Grain Size: Coarse XX Medium

Visible Biological Growth on N, only on base on S, W & E

Stone Condition:
Horizontal Areas

Vertical Areas(SWNE) W side on polished area both red & green growths under surface several areas with flaking

Polished Areas Feld. into clay or open pits, areas of buldges with chipped or flaked minerals with red & green

Unpolished Areas W side copper green discolor. on hornblende pokss. biol. growth

Comments lichen type growth on W polished area 1"sq both crystal flakes around edges clay particles underneath

GRANITE TOMBSTONE INVENTORY

Sample # 7

Name Anna T. Dayton

Date of Death 1898

Approx. Years of Exposure 92

Lot # or Approx. Location near 209

Design of the Monument vertical cross

Orientation of Upright Stones E

Surface Discoloration green on N & W in streaks

Minerals (appearance and color):
Quartz XX
Feldspar XX faint pink
Mica some
Hornblende XX

Grain Size: Coarse ____ Medium XX

Visible Biological Growth green on hornblende horiz & vert E S & W sides

Stone Condition:
Horizontal Areas ____

Vertical Areas(SWNE) ____

Polished Areas Feld only vis on pol not on unpol

Unpolished Areas ____

Comments ____

GRANITE TOMBSTONE INVENTORY

Sample # 8

Name McWilliam James

Date of Death 1972

Approx. Years of Exposure 18

Lot # or Approx. Location across from 089

Design of the Monument low vertical slab, diagonal face

Orientation of Upright Stones E

Surface Discoloration some green & black in small spots

Minerals (appearance and color):

Quartz XX

Feldspar XX salmon

Mica none

Hornblende some

Grain Size: Coarse XX Medium

Visible Biological Growth on pol & unpol green growths on hornb /rough dressed areas spherical green in recessed

Stone Condition:

Horizontal Areas no pitting on unpol

Vertical Areas(SWNE)

Polished Areas minerals under biol growths are pitted also red & green growths btwn crystals

Unpolished Areas

Comments on polished areas many feldspar had brick red stains inside the crystal no biol growth near diff from red biol growth between crystal boundaries

GRANITE TOMBSTONE INVENTORY

Sample # 9

Name W. Elmer Schofield NA/C. Morield Schofield

Date of Death 1944/1960

Approx. Years of Exposure 46

Lot # or Approx. Location 830

Design of the Monument Thick Vert Rough Cut Slab

Orientation of Upright Stones E

Surface deterioration Green

Minerals (appearance and color):

Quartz XX

Feldspar XX Cloudy white

Mica XX Silver

Hornblende XX

Grain Size: Coarse ____ Medium xx

Visible Biological Growth Green on H more than Q on North Side & Protected Areas

Stone Condition:

Horizontal Areas ____

Vertical Areas(SWNE) ____

Polished Areas None

Unpolished Areas ____

Comments No visible signs of deterioration

GRANITE TOMBSTONE INVENTORY

Sample # 10

Name Albert E. Schofield/Margeret Mitchell, wife

Date of Death 1936/1929

Approx. Years of Exposure 54

Lot # or Approx. Location 845

Design of the Monument Vertical Cross w/ carvings

Orientation of Upright Stones e

Surface Discoloration Green & Black

Minerals (appearance and color):

Quartz xx

Feldspar faint amber

Mica xx silver

Hornblende xx

Grain Size: Coarse ________ Medium xx

Visible Biological Growth Spherical green near ground & on N side--mostly on hornblende

Stone Condition:

Horizontal Areas ________

Vertical Areas(SWNE) Protruding areas of carvings are blackened -does not appear to biological

Polished Areas None

Unpolished Areas ________

Comments ________

GRANITE TOMBSTONE INVENTORY

Sample #_ 11 ____

Name_ Ralph Milton Davis Priest _______
Date of Death_ 1979 ________________

Approx. Years of Exposure_ 11 ______

Lot # or Approx. Location_ Across from 774 ________________

Design of the Monument_ Diagonal face low vert. _

Orientation of Upright Stones _ E ______________

Surface Discoloration_ Green on rough cut areas ________

Minerals (appearance and color):
Quartz_ xx ________________ Feldspar_ cloudy white ______
Mica_ xx silver ____________ Hornblende_ xx ____________

Grain Size: Coarse_________ Medium_ XX _______

Visible Biological Growth_ Green on base ______

Stone Condition:
Horizontal Areas________________________

Vertical Areas(SWNE)________________________

Polished Areas_ Black/Green Growth on H ______

Unpolished Areas________________________

Comments________________________

GRANITE TOMBSTONE INVENTORY

Sample # 12

Name Ada M. Walbane
Date of Death 1979

Approx. Years of Exposure 11

Lot # or Approx. Location 946
Design of the Monument Flat rectangular

Orientation of Upright Stones

Surface Discoloration none

Minerals (appearance and color):
Quartz xx   Feldspar xx Pink
Mica   Hornblende xx

Grain Size: Coarse xx   Medium

Visible Biological Growth Green Around Sides

Stone Condition:
Horizontal Areas

Vertical Areas(SWNE)

Polished Areas Brick Red Spots in F Crystals

Unpolished Areas

Comments

GRANITE TOMBSTONE INVENTORY

Sample # 13

Name Walbank William Elizabeth J Date of

Death 1942/1936

Approx. Years of Exposure 54

Lot # or Approx. Location 933

Design of the Monument Vertical Gothic Arch Shaped Slab

Orientation of Upright Stones E

Surface discoloration green near base, black on top & in protected areas & in rough dressed sides

Minerals (appearance and color):
Quartz XX Feldspar XX salmon
Mica XX black Hornblende XX

Grain Size: Coarse ______ Medium XX

Visible Biological Growth black is biol. green grows on hornblende

Stone Condition:
Horizontal areas

Vertical Areas(SWNE) Some pitting with red staining

Polished Areas None

Unpolished Areas

Comments

GRANITE TOMBSTONE INVENTORY

Sample # 14

Name Raleigh William H & Rose Ella

Date of Death 1947/1961

Approx. Years of Exposure 43

Lot # or Approx. Location 929

Design of the Monument Vertical Slab

Orientation of Upright Stones E

Surface Discoloration green on base

Minerals (appearance and color):
Quartz XX Feldspar XX salmon pink
Mica XX black Hornblende XX

Grain Size: Coarse XX Medium

Visible Biological Growth

Stone Condition:
Horizontal Areas

Vertical Areas(SWNE)

Polished Areas Pits with gold clay material

Unpolished Areas

Comments Red staining between crystal edges on polished

GRANITE TOMBSTONE INVENTORY

Sample #__15____

Name__Howard J. Yoast____

Date of Death__1967__________________

Approx. Years of Exposure__23_______

Lot # or Approx. Location__935______________________

Design of the Monument__Diag. Face low vertical slab_

Orientation of Upright Stones _E_______________

Surface Discoloration__Only G on base___

____

Minerals (appearance and color):
Quartz_XX_________________ Feldspar__XX pink____________
Mica__XX black_____________ Hornblende__XX______________

Grain Size: Coarse_________ Medium__XX______

Visible Biological Growth__green on base______________

____

Stone Condition:
Horizontal Areas_________________________________

____

Vertical Areas(SWNE)_____________________________

____

Polished Areas_Areas of dark red staining-near__
pits with gold clay--possible bugs_______________

Unpolished Areas_________________________________

____

Comments____

____

____

____

GRANITE TOMBSTONE INVENTORY

Sample # 16

Name Knott, Edward, Ruth, & Marsden

Date of Death 1945/1976/42

Approx. Years of Exposure 48

Lot # or Approx. Location 916

Design of the Monument Vert. tall slab

Orientation of Upright Stones E

Surface Discoloration Green & Black in protected areas and on North

Minerals (appearance and color):
Quartz XX Feldspar XX amber
Mica XX silver Hornblende XX

Grain Size: Coarse ____ Medium xx

Visible Biological Growth Same as surface discoloration

Stone Condition:
Horizontal Areas Sawn marks partially gone

Vertical Areas(SWNE) Sawn marks still visible

Polished Areas none

Unpolished Areas ____

Comments ____

GRANITE TOMBSTONE INVENTORY

Sample #__17____

Name__Sarah E. Cole____________________

Date of Death_1921____________________

Approx. Years of Exposure__69________

Lot # or Approx. Location__772______________

Design of the Monument_Horiz. curved top____________

Orientation of Upright Stones ________________

Surface Discoloration__green on unpolished area, black around inscription ____________________

Minerals (appearance and color):
Quartz__XX________________ Feldspar_XX salmon ______
Mica__xx black______________ Hornblende__xx______________

Grain Size: Coarse________ Medium__xx_____

Visible Biological Growth______________________________
____

Stone Condition:
Horizontal Areas__no major deter.________________
____

Vertical Areas(SWNE)______________________________
____

Polished Areas______________________________
____

Unpolished Areas______________________________
____

Comments______________________________
____
____
____

GRANITE TOMBSTONE INVENTORY

Sample # 18

Name Frederic Graff

Date of Death 1890

Approx. Years of Exposure 100

Lot # or Approx. Location SW of church

Design of the Monument Horizontal slab

Orientation of Upright Stones

Surface Discoloration Black around inscriptions

Minerals (appearance and color):
Quartz XX Feldspar XX
Mica XX Hornblende XX

Grain Size: Coarse XX Medium

Visible Biological Growth green growths on hornblende

Stone Condition:
Horizontal Areas Many pits some flaking

Vertical Areas(SWNE)

Polished Areas Many pits some flaking

Unpolished Areas

Comments Black around letters worse than on horizontal than diagonal

GRANITE TOMBSTONE INVENTORY

Sample # 19

Name Fracis Sayre Kent

Date of Death 1890

Approx. Years of Exposure 100

Lot # or Approx. Location S of church

Design of the Monument vertical cross

Orientation of Upright Stones E

Surface Discoloration Green & Black, mostly on north & east

Minerals (appearance and color):
Quartz xx Feldspar xx pink
Mica xx black Hornblende xx

Grain Size: Coarse ______ Medium xx

Visible Biological Growth above

Stone Condition:
Horizontal Areas Pitting, sawn marks indistinguishable F not visible

Vertical Areas(SWNE) F still visible

Polished Areas None

Unpolished Areas ______

Comments ______

GRANITE TOMBSTONE INVENTORY

Sample # 20

Name Robert Fulton Blight

Date of Death 1898

Approx. Years of Exposure 92

Lot # or Approx. Location 115

Design of the Monument Vertical Cross w/ Carvings

Orientation of Upright Stones E

Surface
Discoloration see below

Minerals (appearance and color):
Quartz XX
Feldspar XX
Mica XX
Hornblende XX

Grain Size: Coarse ____ Medium XX

Visible Biological Growth Green on North, near base & in protected areas

Stone Condition:
Horizontal Areas F & M still Visible

Vertical Areas(SWNE)

Polished Areas

Unpolished Areas

Comments Pitting on diagonal areas on base.
Blackening around edges on polish design

GRANITE TOMBSTONE INVENTORY

Sample # 21

Name Albert Casey

Date of Death 1903

Approx. Years of Exposure 87

Lot # or Approx. Location S of church along wall

Design of the Monument Vertical thick slab

Orientation of Upright Stones E

Surface Discoloration As below

Minerals (appearance and color):
Quartz XX Feldspar XX cloudy white
Mica Hornblende XX

Grain Size: Coarse Medium XX

Visible Biological Growth Some H areas could have hemi-lichens by-appearance

Stone Condition:
Horizontal Areas Top-unpolished areas almost entirely covered with green & black biol.

Vertical Areas(SWNE)

Polished Areas Many pits with orange clay

Unpolished Areas Rough dressed area also has a thick covering of growth

Comments Stone shaded by three branches above

GRANITE TOMBSTONE INVENTORY

Sample # 22

Name Sidney Hutchinson

Date of Death 1887

Approx. Years of Exposure 101

Lot # or Approx. Location Near 124

Design of the Monument Vertical slab

Orientation of Upright Stones E

Surface Discoloration G & B on base on N side in protected areas

Minerals (appearance and color):
Quartz xx
Feldspar xx light amber
Mica xx light
Hornblende xx

Grain Size: Coarse xx Medium

Visible Biological Growth G on H polished & unpolished

Stone Condition:
Horizontal Areas

Vertical Areas(SWNE)

Polished Areas Some pits much red between crystal

Unpolished Areas F still Visible, no pitting

Comments

GRANITE TOMBSTONE INVENTORY

Sample # 23

Name Helen Williams, Mary Wentworth Leech

Date of Death 1945/1965

Approx. Years of Exposure 45

Lot # or Approx. Location South of church door

Design of the Monument vertical cross

Orientation of Upright Stones E

Surface Discoloration G on W & N, near ground

Minerals (appearance and color):
Quartz xx
Feldspar xx light pink
Mica xx black
Hornblende xx

Grain Size: Coarse ______ Medium xx

Visible Biological Growth As above

Stone Condition:
Horizontal Areas Sawn marks almost all gone mica, some F still visible some pitting

Vertical Areas(SWNE)

Polished Areas None

Unpolished Areas

Comments

GRANITE TOMBSTONE INVENTORY

Sample #__24__

Name__Elizabeth Ralston Welsh__

Date of Death__1885__

Approx. Years of Exposure__105__

Lot # or Approx. Location__Near to S wall of church__

Design of the Monument____

Orientation of Upright Stones____

Surface Discoloration__Much black in unwashed areas, G on N and along base__

Minerals (appearance and color):
Quartz__xx__ Feldspar__xx light amber__
Mica____ Hornblende__xx__

Grain Size: Coarse__xx__ Medium____

Visible Biological Growth____

Stone Condition:
Horizontal Areas__Some pitting__

Vertical Areas(SWNE)____

Polished Areas__No pitting, very little area is polished__

Unpolished Areas____

Comments__Very good condition__

GRANITE TOMBSTONE INVENTORY

Sample # 25

Name Edward Patterson/Isabella Liddon Cox

Date of Death 1910/1907

Approx. Years of Exposure 83

Lot # or Approx. Location NE of church

Design of the Monument Vertical slab

Orientation of Upright Stones E

Surface Discoloration Green on E, N & near base, black on protected unwashed areas

Minerals (appearance and color):
Quartz xx
Feldspar xx salmon
Mica xx black
Hornblende xx

Grain Size: Coarse ____ Medium xx

Visible Biological Growth As above, G mostly on H

Stone Condition:
Horizontal Areas much pitting

Vertical Areas(SWNE) Unpolished, sawn marks still visible

Polished Areas Only letters, some pitting with clay

Unpolished Areas

Comments

GRANITE TOMBSTONE INVENTORY

Sample # 26

Name Samuel Rodman Morgan

Date of Death 1891

Approx. Years of Exposure 99

Lot # or Approx. Location 31

Design of the Monument Horizontal slab w/ raised cross

Orientation of Upright Stones

Surface Discoloration Black

Minerals (appearance and color):
Quartz xx
Feldspar xx
Mica xx black
Hornblende xx

Grain Size: Coarse ____ Medium xx

Visible Biological Growth G on base

Stone Condition:
Horizontal Areas Very pitted

Vertical Areas(SWNE)

Polished Areas Edges of letters & raised cross black very pitted, vertical less than horizontal

Unpolished Areas

Comments

GRANITE TOMBSTONE INVENTORY

Sample # 27

Name Harriet Morgan

Date of Death 1915

Approx. Years of Exposure 75

Lot # or Approx. Location E of church

Design of the Monument Horizontal w/ carvings

Orientation of Upright Stones

Surface Discoloration Black on raised areas

Minerals (appearance and color):

Quartz xx | Feldspar xx

Mica xx | Hornblende xx

Grain Size: Coarse | Medium xx

Visible Biological Growth G on base

Stone Condition:

Horizontal Areas Black appears not to be biological, very pitted, corners of letters broken

Vertical Areas(SWNE)

Polished Areas None

Unpolished Areas

Comments

GRANITE TOMBSTONE INVENTORY

Sample # 28

Name James S. Pierie/George W. Pierie

Date of Death 1882/1885

Approx. Years of Exposure 108

Lot # or Approx. Location E of church

Design of the Monument Thick vertical slab

Orientation of Upright Stones E

Surface Discoloration Very little, some black on base G on sides near ground

Minerals (appearance and color):
Quartz xx Feldspar xx light pinks
Mica Hornblende xx

Grain Size: Coarse xx Medium

Visible Biological Growth G on H

Stone Condition:
Horizontal Areas Some pitting

Vertical Areas(SWNE)

Polished Areas Some pitting & clay, red between crystals some G under surface too

Unpolished Areas Sawn finishing visible on w side, some F into clay

Comments

GRANITE TOMBSTONE INVENTORY

Sample #__29____

Name__John & Barbara J. Warburton__

Date of Death_1877/1888__________________

Approx. Years of Exposure_113________

Lot # or Approx. Location_N of church________

Design of the Monument____________________

Orientation of Upright Stones ______________

Surface Discoloration_Much black in unwashed areas, G on

Minerals (appearance and color):
Quartz_xx______ Feldspar_xx Light amber______
Mica______________ Hornblende_xx________________

Grain Size: Coarse_xx______ Medium__________

Visible Biological Growth_See above____________________

Stone Condition:
Horizontal Areas__Some pitting__________________

Vertical Areas(SWNE)______________________________

Polished Areas__No pitting, very little area is polished

Unpolished Areas______________________________

Comments______________________________

GRANITE TOMBSTONE INVENTORY

Sample #__30____

Name Mary Ann Wilson

Date of Death 1863

Approx. Years of Exposure 127

Lot # or Approx. Location North of Church

Design of the Monument Horizontal w/ carvings

Orientation of Upright Stones ________

Surface Discoloration Black on raised areas

Minerals (appearance and color):

Quartz xx
Feldspar xx pink
Mica xx silver
Hornblende xx

Grain Size: Coarse ____ Medium XX

Visible Biological Growth G on base

Stone Condition:

Horizontal Areas Black appears not to be biological, very pitted, corners of letters broken

Vertical Areas(SWNE) Sawn finish visible on sides

Polished Areas None

Unpolished Areas ________

Comments ________

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